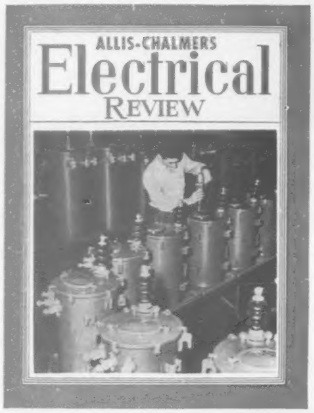
ALLIS-CHALMERS

Electrical Review

Fourth Quarter, 1948



LIGHT AND POWER in the making for the homes and farms of America. Thousands of potential kva a day pass down the distribution transformer assembly lines at the Allis-Chalmers Pittsburgh Works.

Operator is tightening covers on 10-kva, 7,200-volt rural line transformers prior to final painting. Increased production of small transformers for rural power lines indicates rural America's desire for better living and working conditions through wider application of electricity.

★

Allis-Chalmers

Electrical Review

Vol. XIII No. 4

Indexed regularly by Engineering Index, Inc.

Issued quarterly. Subscription rates: U. S., Mexico, and Canada, $2.00 per year; other countries, $3.00.

Address Allis-Chalmers Electrical Review, Milwaukee 1, Wisconsin.

Printed in U. S. A.

★

ALLIS-CHALMERS Electrical REVIEW

★

Contents

★

AFTER GRADUATION: OPPORTUNITY

"Graduates today, engineers tomorrow," is industry's offer.

FRASER JEFFREY
Assistant to Chief Electrical Engineer
Allis-Chalmers Mfg. Co.

GRADUATION, then what?

Thousands of graduating engineers are faced with this perplexing problem. Although confident that each will be able to adjust himself to the exacting demands of industry, many view the future with apprehension. Finding the desired niche in a highly competitive world jolts many of them into momentary helplessness. The world seems cold and success seems a long and heartbreaking distance away from the graduation stage.

It's not as bad or hopeless as the anxious graduate may think. There is a definite place for the neophyte engineers, for industry needs them and is willing to go more than halfway to show them the right road towards their professional goal. The field of engineering is limitless, the opportunities infinite. But the price is determination, alertness, hard work, modesty, and the willingness to take anything and everything in stride during the formative period.

What does engineering offer?

Engineering is much too vast a field to limit opportunities; so much so that the various component groups have tended to become highly specialized. And yet, there is no particular difference between an electrical and a mechanical engineer when each has been well-grounded in engineering fundamentals.

The difference between a chemist, a metallurgist, a geologist, a civil and an electrical or mechanical engineer may be enough in curricular background to make it difficult to orientate all of them to a common base. Chemical engineers are vitally needed for specialized work on metals, insulation materials, ceramics, oils, varnishes, greases, etc. The civil engineer is in demand by industries supplying road equipment, tractors, power lines, oil line equipment, etc. The opportunities are there; they need just be recognized and grasped. But how?

After college comes education in the "school of engineering practice." As in other fields of work, the first few years are the toughest. They demand persistence and perseverance, willingness to accept philosophically various engineering operations and routine tasks no matter how trivial and chafing they may seem, and an unconditional willingness to accept and respect the counsel of superiors as a sincere desire on the part of more experienced men to help beginners on their professional journey. All of these help mold judgment, one of the most important qualifications for engineering positions of responsibility in the varied and allied branches of engineering.

Most of the graduates have a vague idea of what they would like to do. Their main concern, however, is how to get into their currently favored field. Counsel for breaking into their chosen line of work varies as much as the number of advisors giving it. Many do not realize that industry has taken steps to help them on their way.

Leading industrial concerns have organized elaborate and

TODAY, INDUSTRY SELECTS engineers scientifically. Further training in specific fields of engineering is determined by intelligence and aptitude tests and interviews conducted by expert professional counsellors.

GRADUATE TRAINING COURSE provides successful aspirants with sound theoretical and practical education. Company specialists conduct instruction, using actual or working models of equipment for greater teaching effectiveness.

highly effective training courses to orientate young engineers towards the most suitable pursuit. These are not haphazard projects, but thoroughly planned post-graduate courses. It does not matter whether the man is an electrical or a mechanical graduate, because by these special training courses and the additional curricular studies made available to them, an electrical graduate may readily become specialized in some mechanical problem, or vice versa. Since no two engineers have the same interest, abilities and personalities any more than they have the same fingerprints, these courses are modified to prepare each one for the position he is best suited to fill.

Young engineers have some idea of the phase or kind of engineering they prefer. Unfortunately, this preference is oftentimes based on hunches rather than on something concrete or substantial. Many feel they would like sales work or design, or some other line simply because they *think* they would like that type of work and not because they are physically, mentally or psychologically fitted for that specific work.

Industry "picks" and "fits" engineers

For these reasons, larger industries attempt to evaluate each graduate's personal characteristics to help guide him into the most appropriate field of engineering. Some engineers, too many of them as a matter of fact, believe that they can change their line of work at any time and be just as efficient as a man who has spent a long period of time in one type of work. Only costly and often heartbreaking experience emphasizes the folly of overconfidence.

Just how does a large concern go about polishing a graduate engineer? For one thing, he is assigned to many varied but allied jobs in the shops during the first stages of his industry training period. This is usually followed by several more months of work in the various engineering and sales departments. The graduate has continual counselling to help him make a final decision as to what his future field will be. In the meantime, he has been attending the graduate school, which is a part of the training course. Credits thus obtained can be applied toward a master's degree in his chosen future field, if he so desires.

These programs are not restricted to industrial learning and experience only. Men are afforded every opportunity to advance themselves in social as well as professional accomplishments. They are encouraged to join the various professional societies and associations and take part in discussions with older members whose advice and observation help to mature budding engineers. Social aptitudes are given ample opportunity to expand through these informal contacts. Getting along with people is another important requisite which helps considerably to advance graduates towards success.

Is industry over-playing the importance of graduate training courses? Are they necessary and, most of all, do they accomplish what they are intended for? Charles F. Scott, past-president of the A. I. E. E. and professor of electrical engineering emeritus at Yale University and president of the National Council of State Boards of Engineering Examiners, dispelled all doubts many years ago when he wrote a small brochure entitled "What Is Engineering Experience?" The brochure carried a notation that its contents would be of special interest to recent engineering graduates and other young engineers.

Mr. Scott cited the case of a letter a young applicant had written to the secretary of a state registration board asking why they had refused to grant him a license as a professional engineer in view of the fact that he had a diploma and *five* years' experience while the requirement was a diploma and *four* years' experience. The reply of the secretary was to the effect that the nature of the work which the candidate had been doing had not added to his professional development and that his experience was not satisfactory to the board. Profiting from this advice of many years ago, graduate training courses now instituted by industry provide men with the well-rounded experience required.

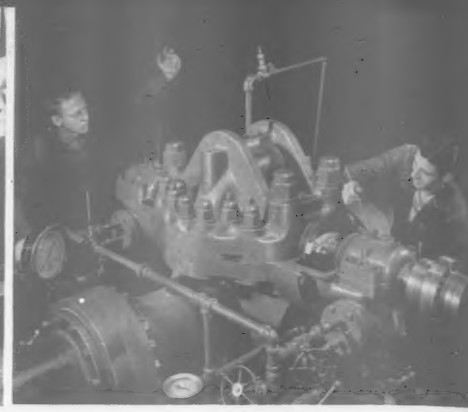
Appearance, personality count, too

Since an engineer will be a personal representative of the concern he works for, industry demands pleasing appearance and personality. About a year ago, a young man was sent up by the employment manager to the head of one of the engi-

SOCIAL ACTIVITIES HELP graduate engineers to relax and to develop social ease. At right, engineering graduates are connecting a large transformer in the shops for testing, one of many valuable phases of the course.

RECTIFIER LABORATORY work familiarizes engineers with actual and latent possibilities of equipment during experimental development stages.

LEISURE TIME is well spent. "Ham" sets provide instruction and pleasure, bringing home a bit closer to graduates who may be from other lands.



TEST FLOORS for electrical and associated equipment enables graduate engineers to learn construction and operation details of equipment.

neering departments in a large industrial concern. He had a college degree and appeared to have had a fairly good grounding in engineering fundamentals. However, his shirt collar was soiled, his fingernails dirty, and he lacked the social grace to remove his hat during the interview. Apparently, he was maladjusted. Needless to say, he did not get the job.

Industry wants, in addition to a well-grounded training in fundamentals and a degree from an accredited college, young men and women who are neat in appearance, alert, and who have the ability to get along with other people. They must also be willing and able to do their jobs to the best of their ability.

A young engineer cannot be accorded full responsibility for the electrical or mechanical design of a motor, generator, transformer, switch, or some other piece of equipment immediately upon joining a firm. It takes years of experience to acquire this ability. The designer has to have work experience in many things such as rectilinear field mapping, heat transfer, air flow and fans, sound levels, critical speeds, mechanical stresses, reactance and stability factors, etc.

Even a designing engineer should, in due time, acquire the ability to analyze costs, become acquainted with sequence operations in time study and the various levelling and allowance constants that are used and how they, in turn, are calculated. He should become familiar with piecework rates and incentive systems, with labor efficiency problems and labor relations, as well as business trends, and wages and materials cost indexes. These things are not so necessary for the research man working in pure science, but then they do him no harm either. Although industry is patient in many ways, it does demand that its young men and women be on their professional and social toes at all times.

The following case record indicates the caliber of engineers industry is looking for and spending large sums to train.

Some time ago, a certain industry built a pump unit that was driven by a 500-hp, 2,200-volt, three-phase induction motor for installation in a steel mill. Upon arrival at the mill the equipment was set up in a building which already had a number of similar units in operation.

On about the tenth day of operation the new motor developed a coil failure which put it out of commission. The damaged coils were replaced and the unit put back in operation. Not very long after this another failure occurred in a totally different part of the winding. The steel people wrote a letter stating that the coil insulation was defective, as none of the other similar equipment operating in the same room had ever given any trouble of this kind. Therefore they demanded that an entirely new winding be installed immediately.

The manufacturer complied with the request. However, his engineers were not convinced that the winding was actually defective. They did not know exactly what the trouble was, but they were determined to find out. Before the rewound machine was started up again, three needle spark gaps were installed, one side of each being connected to the copper leads of each terminal, the other sides being connected to ground. The needle gaps were spaced for a breakdown of 4,000 volts, and a thin piece of white paper was placed between each gap so that a breakdown of the gap would be indicated on the paper.

The normal operating voltage of the motor was 2,200 volts. A few days later a spill-over was indicated on one of the gaps. The needles were next spaced for 6,000 volts. Again a spill-over occurred. The same thing occurred at 7,000 volts. By this time it was definitely determined that there were dangerous voltage surges occurring on this particular feeder that were not occurring on feeders of the other motors because the surge impedance of the motor appeared to be in resonance with this particular circuit.

A study of the whole system resulted in establishing a better grounding of the neutral of the power generating equipment in the plant, and a change in some of the surge equipment on the bus structure. Because of these changes, the unit has been operating without trouble to this day.

The little incident shows that industry needs engineers whose business it is to be alert at all times. Only enlightened and intelligent design and application foster progress and good will. Industry, therefore, is more than willing to give young engineers a chance to "find" themselves in their future field through its graduate training courses.

Conclusion—"opportunities galore"

Engineering has progressed rapidly. There is so much to be known about all the actions and reactions of different combinations of new materials, such as the high temperature silicone insulations; electrical surges and other transient conditions; air-blast circuit breaker actions; critical speeds; natural and forced periods of vibration; and so forth, *ad infinitum*. The new fields mentioned here do not even enter into the field of atomic energy.

Electrical and mechanical engineering alone offers vast opportunities and new frontiers. There's the matter of high voltage d-c transmission where the high voltage might possibly be furnished by rectifiers with electronic control; there is also the highly efficient mechanical rectifier; the gas turbine for electric propulsion of ships and rail locomotives; electronic regulators and exciters; phase angle switching, and many other things too numerous to mention.

Graduates, take your pick, but pick wisely. Industry asks that you supply the ambition—it will do the rest.

PULPIT CONTROL in an eastern steel mill regulates the pulse of the finishing train; starting, accelerating and stopping operation at the touch of the operator's hand. Finishing mill control system includes Regulex exciters controlling the 50-kw exciters for the fields of the six 3,000-kw main mill generators shown on pages 16 and 17.

Changing taps under load

L. W. SCHOENIG
Transformer Division
Allis-Chalmers Mfg. Co.

TRANSFORMERS with load-ratio control equipment are becoming more and more popular on present-day power systems. The transmission of larger blocks of power results in greater voltage drops which, together with customer requirements for more accurately controlled voltage, necessitates the use of load ratio control equipment. Systems are becoming more and more complex and interconnected with the result that generator voltage control in itself is not sufficient to maintain closely regulated voltage.

Load-ratio control equipment is used on transformers to change the turn ratio or voltage or to shift the phase without interrupting the load. This equipment should not be confused with no-load tap changing equipment with which the transformer must be completely de-energized when the turn ratio is changed.

New design spurs acceptance

Transformers with load-ratio control equipment have been used sporadically for the past 30 or 40 years, but it has not been until recently that the importance and reliability of load-ratio control equipment was fully appreciated. The first load-ratio control equipment was cumbersome, clumsy, slow operating. Because it was an innovation, most operators regarded it with skepticism. Marked improvements in design and construction, however, reversed this unfavorable attitude.

Need for more accurate voltage regulation spurs acceptance of load-ratio control.

Today, load-ratio control equipment is universally accepted and systems are designed to utilize the advantages obtained by its use. For instance, it can be used to correct voltage drop in transmission lines to the transformer or regulator, line drop from the transformers or regulators to the load, fluctuation in voltage due to variations in load, and also to control the flow of active and reactive power.

LV winding preferred location

In transformers, the load-ratio control mechanism is usually located in the low voltage winding. However, it is sometimes advantageous to locate it in the neutral of the high voltage winding if it is wye-connected and operated solidly grounded. Voltage surges due to switching and lightning are less severe in the low voltage and the neutral of high voltage windings.

Another very important reason for these locations is the variation in cost of load-ratio control equipment for the different voltage classes. A 15-kv load-ratio control mechanism is less expensive to manufacture than one rated 25-kv or higher (Figure 1). It is not always possible to use a 15-kv class mechanism in the neutral of a winding because the voltage class of the winding determines the insulation class of the load-ratio control mechanism. The following table gives the mechanism insulation class for use in the neutral of various winding voltage classes.

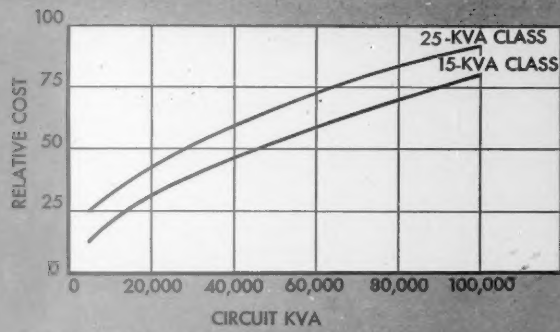
WINDING INSULATION CLASS (KV)	LOAD-RATIO CONTROL INSULATION CLASS (KV)
34.5 and Below	8.66
46 Through 69	15
92 Through 115	25
138 Through 161	34.5
196 Through 230	46

Trend is toward ± 10 percent regulation

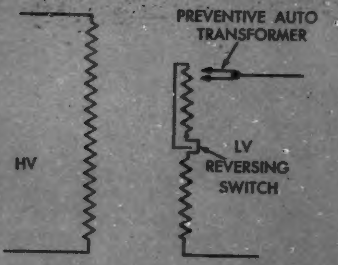
Most transformers with load-ratio control equipment and feeder voltage regulators are supplied with a range of regulation of 20 percent (10 percent raise and 10 percent lower) in thirty-two ⅝ percent steps. Occasionally, load ratio control mechanisms on power transformers are furnished with 1¼ percent steps, but these are rapidly giving way to the smaller steps which regulate more accurately with considerably less burden on the tap changing contacts due to lowered voltage between taps. As a result, considerably less frequent inspection is required.

Two basic circuits fill needs

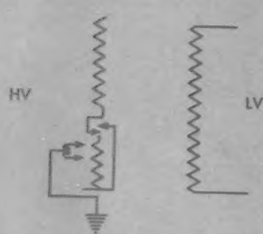
There are many load-ratio control circuit variations. However, two fundamental types, one with taps directly in the main winding, the other used with a series transformer, are the most widely used. When the current and voltage to be interrupted are not too great, the load-ratio control mechanism is located directly in the winding. For higher voltages or currents a series transformer is used. Figures 2 and 3 show load-ratio control transformers with taps directly in the winding: Figure 2, with the load-ratio control equipment in the low voltage winding; Figure 3, with the equipment in the high voltage neutral. A series transformer functions (as shown in Figure 4) like a current transformer to reduce the current which the mechanism must interrupt. Figure 5 shows a typical series transformer connection in a low voltage winding.



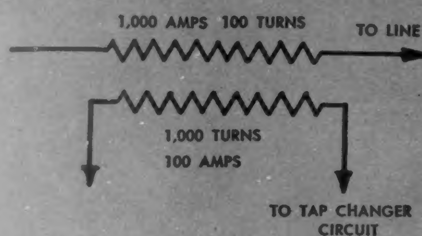
RELATIVE COST of 15-kv and 25-kv class load-ratio control mechanisms for various circuit kva outputs. **(FIGURE 1)**



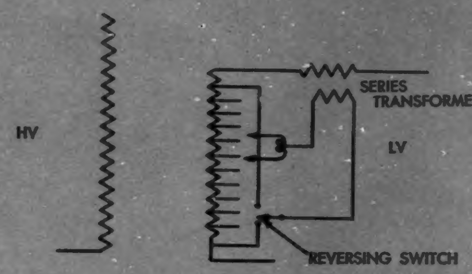
LINE DRAWING of load-ratio control transformer with taps in low voltage winding. **(FIGURE 2)**



THIS LOAD-RATIO control transformer has taps in high voltage neutral. **(FIGURE 3)**



SERIES TRANSFORMER, diagrammed above, operates like a current transformer. **(FIGURE 4)**



SERIES TRANSFORMER of this load-ratio control unit is in low voltage winding. **(FIGURE 5)**

Interrupting kva determines mechanism

The interrupting capacity of a load-ratio control mechanism is determined by the speed of contact separation, sizes, shape, and contact material, and the insulating medium (oil, air, etc.).

The interrupting kva is the product of the current to be interrupted and recovery voltage (voltage which attempts to restrike the arc). The lower the recovery voltage, the higher the current which can be interrupted. Conversely, the higher the recovery voltage, the lower the current which can be interrupted. If either the voltage or current exceeds the interrupting ability of a load-ratio control mechanism, either a larger capacity mechanism or a series transformer must be used.

The current in the tap changer circuit is decreased by properly adjusting the turn ratio of the series transformer. As the current in the tap changer circuit is decreased, the recovery voltage is increased. The kva to be interrupted is the same when a series transformer is used or the taps are directly in the main winding, however the current (and voltage) to be interrupted is changed.

The regulating taps (eight in number) in Figures 2, 3, and 5 are brought to stationary contacts on the dial switch of the load ratio control mechanism. With this arrangement, 16 positions can be obtained by changing the position of the moving contact from normal position (with both moving contacts on one stationary contact) to a bridging position (when each of the moving contacts is on an adjacent stationary contact). The use of the reversing switch doubles the tap range and number of positions.

Autotransformers maintain current flow

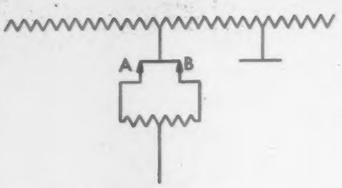
All load-ratio control transformers and feeder voltage regulators require the use of a reactor or preventive autotransformer. Without it, load ratio control would not be practical because load current would be interrupted while taps were being changed. It must be designed to operate satisfactorily for three different conditions—normal, intermediate, and bridging (Figures 6, 7, and 8, respectively). Each condition requires special design consideration.

The preventive autotransformer is mid-tapped and usually designed as a three-legged core type unit for three-phase transformers, or as a two-legged core type unit for single-phase transformers. When the preventive autotransformer is on normal position, half of the load current flows through each half of the winding. The winding is well interleaved with the result that the reactance in this position is virtually zero. Practically the only voltage drop is the IR drop due to one-half load current flowing in each half of the preventive autotransformer.

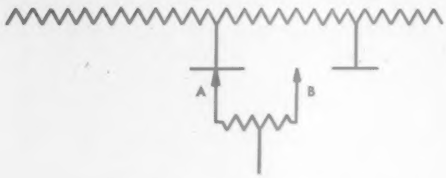
When operating on an intermediate position, all of the load current flows through one-half of the preventive autotransformer, exciting it to normal operating voltage (a voltage equal to that between stationary contacts). Preventive autotransformers are designed with the exciting current equal to a certain percentage of the load current. Air gaps are inserted in tongue of the core to increase the exciting current to this value. If the normal exciting current were too low, the core would become excited to a very high flux density and, as a result, a high voltage would appear across the ends of the preventive autotransformer during the transition period. The value of this voltage would depend on the characteristics of the core iron, normal flux density and the extent of the over-excitation of the core. This voltage would be many times normal if the normal exciting current was low.

When the preventive autotransformer is in the bridging position, Figures 9a and 9b, the load current divides equally, half flowing through each half of the preventive autotransformer. In addition to the load current, exciting current flows in the preventive autotransformer. This very low power factor circulating current is limited essentially by the impedance of the preventive autotransformer. The power factor of the circulating current can be considered to be zero lagging.

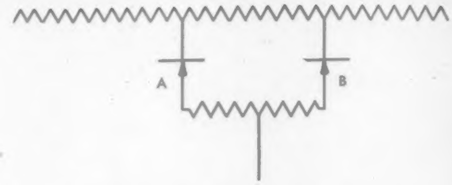
The voltage, current, and kva interrupted depend upon the direction of motion of the load ratio control mechanism and the position of the moving contacts on the dial switch. When the moving contacts move from the bridging position, the voltage, current, and kva interrupted are greater than when moving from a normal position since the exciting current



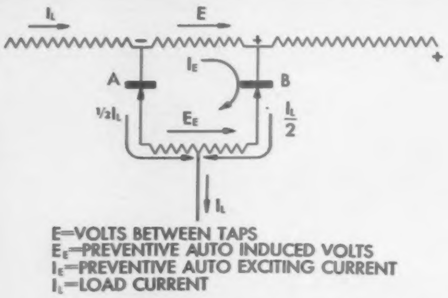
NORMAL OPERATING position shown has both moving contacts on one stationary contact. (FIG. 6)



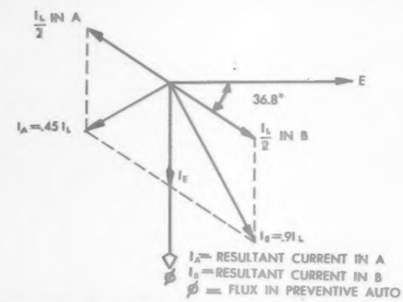
INTERMEDIATE OPERATING position requires special design consideration. (FIGURE 7)



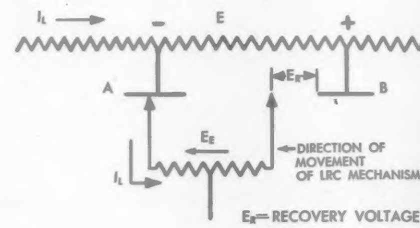
TRANSFORMER in bridging position has a moving contact on each stationary contact. (FIGURE 8)



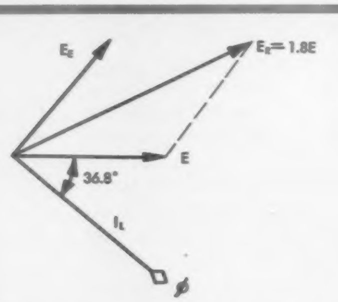
WINDING ARRANGEMENT and current flow for the bridging position of a preventive autotransformer are diagrammed above. (FIGURE 9a)



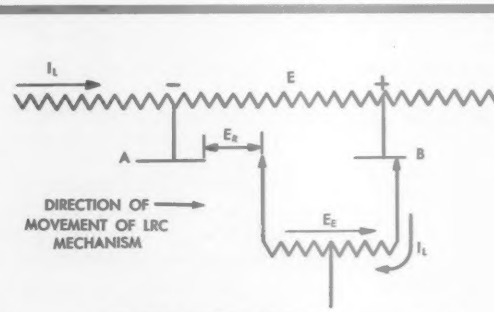
VECTOR DIAGRAM of voltage and current flow for bridging position of preventive autotransformer with load power factor of 0.8 lag. (FIGURE 9b)



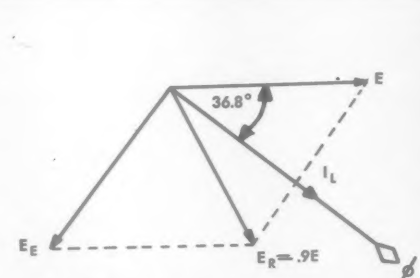
WINDING ARRANGEMENT and current flow while load-ratio control equipment of preventive autotransformer is in intermediate position. (FIG. 10a)



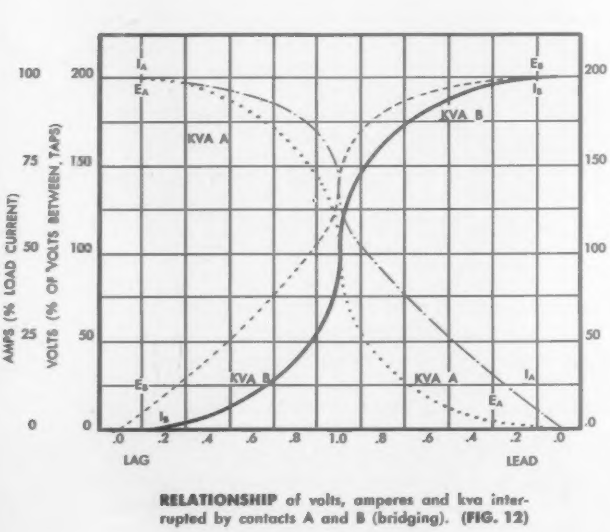
RECOVERY VOLTAGE development when load-ratio control equipment is in intermediate position. Power factor of load is 0.8 lag. (FIGURE 10b)



WINDING ARRANGEMENT and current flow when load-ratio control equipment of autotransformer is in an intermediate position. (FIG. 11a)

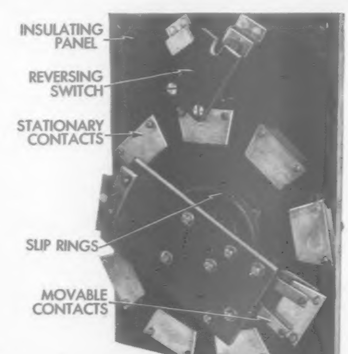


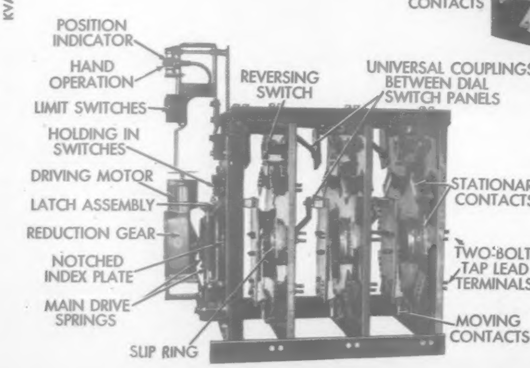
VECTOR DIAGRAM showing development of recovery voltage when load-ratio equipment is in intermediate position. (FIGURE 11b)

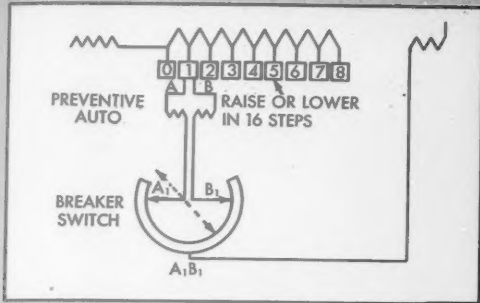


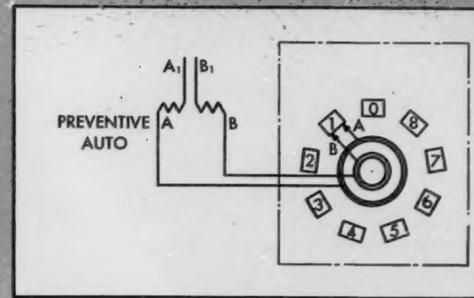
RELATIONSHIP of volts, amperes and kva interrupted by contacts A and B (bridging). (FIG. 12)

LIGHTER DUTY load-ratio control consists of a spring-actuated, quick-break drive (below) and dial switch (right). (FIGURES 13a and 13b)



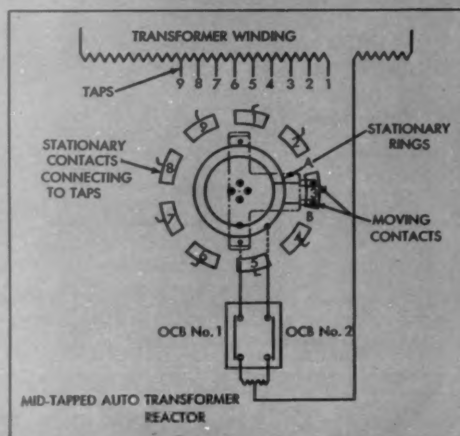


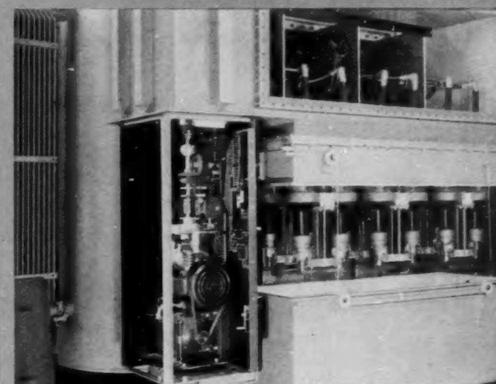




CONNECTION diagram (left) of a heavy duty load-ratio control mechanism and, at right, a heavy duty switch. (**FIGURES 14a and 14b**)

QUICK-BREAK mechanism of three-phase rotary breaker provides efficient and economical service for interrupting currents and voltages beyond those which can be interrupted by finger contacts. (**FIG. 14c**)





HEAVY DUTY load-ratio control equipment shown above is used for regulating voltage of a 15,000-kva, three-phase, 38,000-volt transformer. Schematic diagram at left shows the arrangement of operating parts. (**FIGS. 15a and 15b**)

appreciably affects the voltage, current, and kva interrupted while moving from the bridging position. Figures 10a and 10b show the mechanism in the process of changing taps and the vector diagram of the resulting voltages. Figures 11a and 11b are similar except that the load-ratio control mechanism is moving in the opposite direction.

As shown in Figure 12 the voltage, current, and kva interrupted by the moving contacts vary appreciably with the power factor of the load. It can be seen that the current interrupted by each of the moving contacts can vary from zero to a value equal to load current, whereas the voltage interrupted varies from zero to 200 percent of the voltage between stationary contacts. The kva interrupted also varies from zero to 200 percent of normal. When the mechanism moves from normal to a bridging position, the current interrupted is always about 50 percent of load current, the voltage equal to that between stationary contacts, and the kva is about 50 percent of normal.

Light duty mechanisms

Two general types of load-ratio control mechanisms are used on feeder voltage regulators and load-ratio control transformers. The first type is the lighter duty mechanism which interrupts the voltage and current and changes the turn ratio directly on the dial switch. The second type is the heavier duty mechanism which utilizes separate breakers to interrupt the current synchronized with the switch which changes the turn ratio.

The lighter duty mechanism consists of a spring actuated quick-break driving mechanism and a dial switch for each phase. A typical mechanism is shown in Figure 13a and a dial switch showing stationary and moving contacts is shown in Figure 13b. The quick-break mechanism, being spring actuated, drives the moving contacts very rapidly. The speed of contact separation, together with the arc resisting material, of which the stationary and moving contacts are made, reduces contact deterioration to a minimum and assures long, trouble-free life with these mechanisms.

Heavy duty mechanism for large loads

The current and voltage which can be interrupted by the finger type contact of the lighter duty mechanism is limited. To exceed this limit would require very large contacts and dial switch assemblies. It is more practical and economical when this limit is exceeded to use separate breakers to interrupt the current and voltage and dial switches to change the turn ratio. Several types of separate breakers are used in the heavier duty mechanisms. Among them are rotary circuit breakers, as shown in Figure 14a to 14c and conventional oil circuit breakers. Both of these are actuated by quick-break spring driven mechanisms.

In the heavier duty mechanisms, like the lighter duty type, the speed of contact separations and large contacts of arc resisting material mean relatively little contact deterioration and long, trouble-free operation. Figure 15a shows a heavy duty mechanism during assembly, with the oil tank lowered for inspection. Schematic diagram shows arrangement of working parts in Figure 15b.

Future holds promise

Load-ratio control equipment has come a long way from the early slow-operating, bulky mechanisms of 40 years ago. Its success has come through constant improvements in a multitude of little details and by avoiding radical design changes without adequate field tests to ensure complete dependability. Transformer banks with capacities far in excess of 100,000 kva have already been equipped with load-ratio control and the practical limit is far from reached at this point.

Rx Interlocks for Switchgear

Operating needs should be known before interlocks are selected.

ALBERT EWY
Engineer, Switchgear Section
Allis-Chalmers Mfg. Co.

INTERLOCKS for metal-clad switchgear provide safety to operating personnel, prevent damage or excessive maintenance to equipment or expensive delays in production. Today, industry considers interlocks essential. The different types have been developed to meet specific operating conditions with the intention of reducing the number and frequency of operating errors. It is essential, therefore, that when interlocks are selected all the factors be considered in their design.

An interlock is a device applied to two or more movable parts preventing or allowing a movement of one part only when another is locked in a predetermined position. The following general requirements should be considered in the design of interlocks:

(1) What is the interlock to accomplish?
(2) Where is the equipment going to be used?
(3) Is it reliable?
(4) Will it function so it will not interfere with the normal operation of the parts being interlocked?
(5) If an electrical interlock is used, will the failure of the supply cause serious inconvenience or defeat the interlock?
(6) Will added functions due to the addition of the interlock inconvenience the operator?
(7) Is it reasonably difficult to defeat the interlock?
(8) Are the parts of the interlock designed so they are sufficiently strong mechanically?
(9) What effect will temperature and weather conditions have?
(10) Is it simple to install and operate?
(11) Will the cost of the particular interlock selected be reasonable?
(12) Will it accomplish the desired result?

Conditions determine type

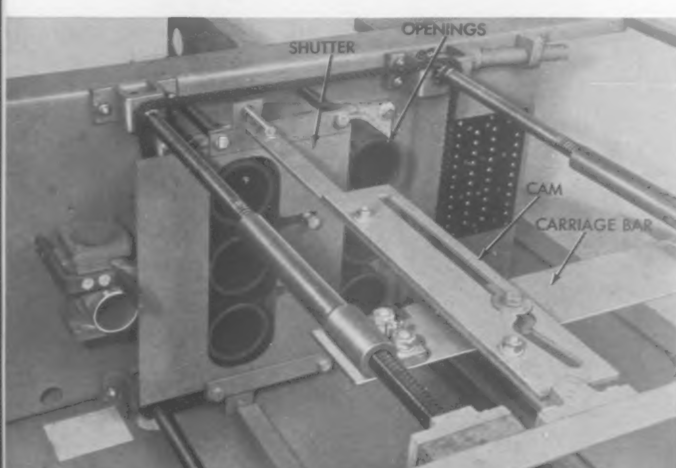
Interlocks may be classed as one of the following types, or combination of these types: mechanical, electrical, and key. Each type of interlock has its advantages when properly designed and applied. But it is difficult to select the proper type unless all factors are considered.

Mechanical interlocks are considered very reliable and, if properly designed, difficult to defeat. However, they become impractical when the parts to be interlocked are too far apart. At times, it is also impossible to prevent interference with the normal operation of the items being interlocked. They are also unsuited for sequence interlocking operation because of the extreme complications that would be encountered in its application.

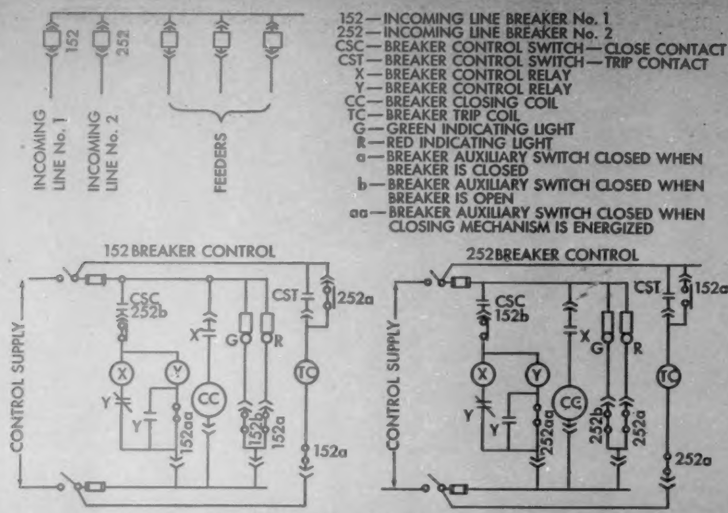
Electrical interlocks are more easily accomplished than mechanical interlocks when parts are relatively far apart. Also, interlock sequences may be set up which are automatic and do not produce inconveniences to normal operation of parts. Care must be exercised in the design to obtain reliability. The loss of the electrical supply should not defeat the interlock. The application of an electrical interlock limits its use to a location that has an electrical supply. Failure of the electrical supply will cause the devices being interlocked to become inoperative.

Key interlocks are similar to mechanical interlocks in that they may be designed for great reliability. In addition, units may be interlocked that are relatively far apart. The manufacturers of key interlocks supply locks with keys that fit only certain locks to perform specific interlock functions.

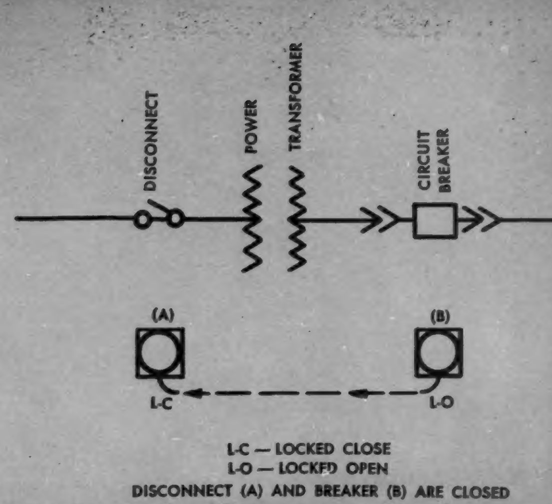
There is little danger that identical keys will be furnished for the same function and thus defeat the interlock when the designer gives complete information to the key interlock manufacturer. The manufacturer then carries a complete record of the various keys supplied with each job.



CARRIAGE BAR supports breaker when it is raised to connected or disconnected position. Cam provides desired travel to metal plate or shutter to cover openings when breaker is removed. (FIGURE 1)



TYPICAL INTERLOCK for two incoming line breakers. **(FIGURE 2)**



LINE DRAWING of typical key interlock. **(FIGURE 3)**

The chief disadvantage of key interlocks is the inconvenience to the operator, since he has to convey the key from one interlock to another. This can cause serious inconvenience when the devices being interlocked are a considerable distance apart. It may also be considered impractical because of the time factor involved in conveying the key or the time lost in locking one device and unlocking another for operation. For this reason, key interlocks are not considered suitable for automatic control.

Interlocks stop operating accidents

The following are some typical applications where it is desirable to apply interlocks to give proper protection:

(1) Prevent an arc on the primary disconnecting contacts when a circuit breaker is moved to either the connected or disconnected position of the structure. (*Typical solution*—Apply an interlock so that the breaker is held open until it is in the connected position.)

(2) Prevent removing the tank of an oil circuit breaker while the breaker is in the structure and accidentally making contact with parts that are live.

(3) Prevent an arc on a disconnect switch as it is operated, unless its associated breaker or breakers are open.

(4) Prevent energizing a circuit by unauthorized personnel by locking the breaker in the disconnect position.

(5) Prevent overloading a 600 ampere breaker by accidentally inserting a 600 ampere breaker into a 1200 ampere unit, or inserting a 600 or 1200 ampere breaker into a 2000 ampere unit.

(6) Prevent an arc on the primary disconnecting contacts of a control transformer mounted on a drawout carriage by arranging to open the secondary circuit before the primary disconnect contacts can be parted.

(7) Prevent contact from being made to potential transformer fuses by the operator until the primary contacts are separated at a safe distance.

(8) Prevent an arc on the primary contacts of disconnect bus arrangement normally called a "Dummy" movable portion as it is inserted in a breaker position and connected or disconnected to the bus connections.

(9) Prevent closing a generator breaker by an operator unless he is in the procedure of synchronizing by interlocking the breaker with the synchronizing switch.

(10) Prevent closing a generator breaker unless the generator field breaker is closed.

(11) Prevent an operator from getting at a circuit breaker unless the breaker is open by interlocking the door of the housing with the breaker.

(12) Prevent closing the secondary breaker of a power transformer that has been tripped out due to excessive transformer temperature until the transformer has been cooled to a safe operating temperature.

(13) Prevent reclosing a generator breaker when differential relays protecting the generator windings have operated and do unnecessary additional damage to the winding.

(14) Prevent closing a breaker feeding a motor when the operating voltage is not normal.

(15) Prevent tap changing mechanism of a power transformer from changing taps when any of the feeders from this transformer has a fault and is going through a reclosing cycle to eliminate this fault.

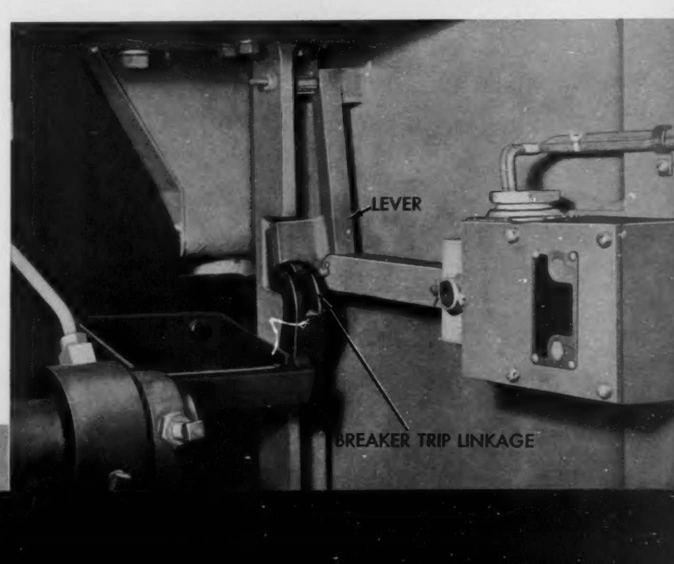
(16) Prevent energizing a feeder circuit by locking the breaker in a disconnect position.

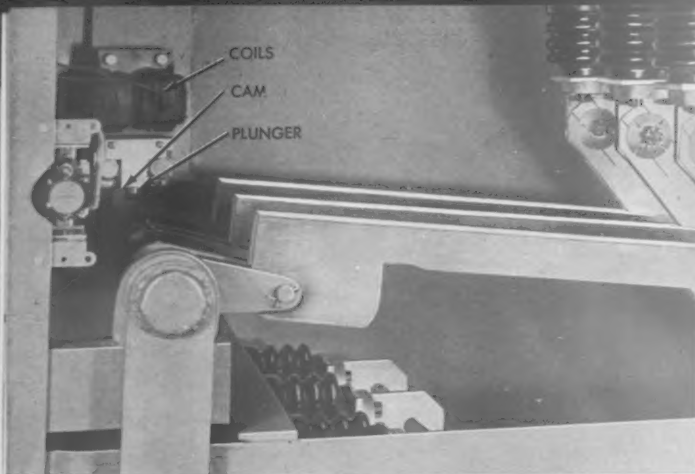
(17) Prevent closing a circuit breaker unless the phase rotation between two power lines is the same.

Typical application schemes

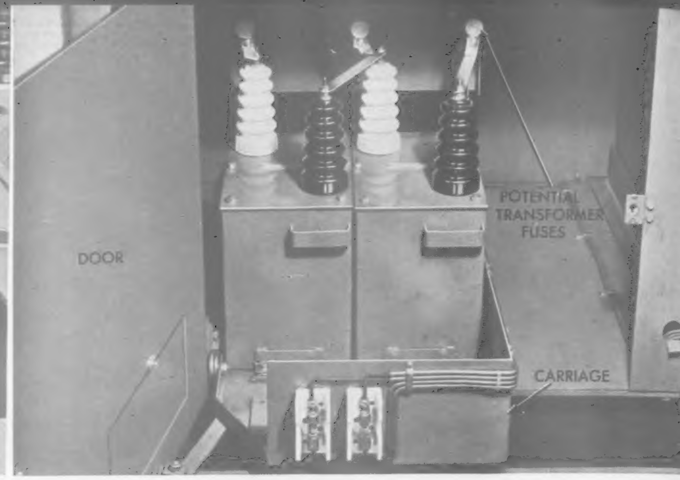
Many more conditions could be listed to which mechanical, key, or electrical interlocks can be or are applied. An outline of all the known methods for interlocking high voltage equipment would probably fill a book. However, a study of a few of the most commonly used schemes in metal-clad switchgear

KEY INTERLOCKS are designed for specific needs. Mounted on the switchgear unit, this interlock prevents closing of breaker and operation of electrical equipment, providing safety for operator and equipment. **(FIG. 4)**





ELECTRICAL INTERLOCK prevents opening of three-pole, double-throw disconnect switch when breaker is closed. Opening of switch would cause uncontrolled arcing, endangering equipment and personnel. **(FIGURE 5)**



SAFETY DEVICES prevent accidents when changing potential transformer fuses, as opening the door to potential transformer chamber automatically disconnects transformers from live bus. **(FIGURE 6)**

will supply a basic understanding of the problem of protection and how it can be solved.

Figure 1 shows a typical mechanical interlock found in a metal-clad circuit breaker structure. Its function is to close off the openings of the primary disconnect contacts so that if the breaker is removed from the structure or lowered to the disconnect position, a metal plate is moved to cover the openings and prevent accidental contact with the primary contacts.

A typical electrical interlock between two incoming line breakers which permit only one breaker to be closed at a time is illustrated in Figure 2. The two incoming lines are not in synchronism and it is necessary that at no time the two breakers be closed at once. This is accomplished by placing auxiliary switches in the closing circuits and the trip circuits of the breakers being interlocked.

Auxiliary switches 252b is placed in the closing circuit and 252a in the trip circuit of incoming line No. 1, breaker 152, and auxiliary switch 152b is placed in the closing and 152a in the trip circuit of incoming line No. 2, breaker 252. Auxiliary switches 152b and 252b on the breakers are closed when the breakers are open, auxiliary switches 152a and 252a are closed when the breakers are closed. Auxiliary switches are placed in the trip circuits to prevent closing the breakers by a manual closing lever.

Figure 3 shows a typical key interlock between a primary disconnect and a secondary circuit breaker, the object being to prevent opening of the disconnect under load unless the breaker is locked open. The illustration shows the key with lock on the breaker. The lock is open, which is a normal operation. To open the disconnect, it is necessary to remove the key from the lock at the breaker. The key can only be removed when the breaker is open. The key is then inserted in the lock at the disconnect, and turning it will unlock the disconnect, permitting the disconnect to be opened or closed. The key cannot be removed unless the disconnect is in the fully open or closed positions.

After the disconnect is operated, the key is removed from the lock at the disconnect and inserted in the lock at the breaker. Turning the key will again unlock the breaker and the breaker operation is normal.

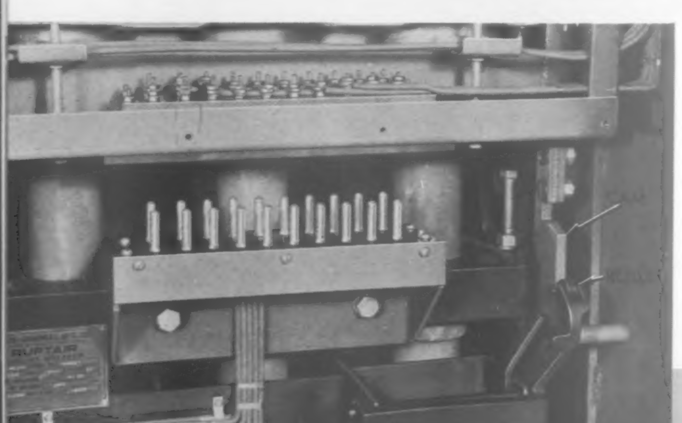
A key interlock mounted on the breaker is shown in Figure 4. To remove the key, it is necessary to pull the lever forward. The lever then moves the breaker trip linkage to the trip-free position, preventing the breaker from being closed. An electrical contact in the interlock housing is wired in the closing circuit of the breaker to prevent electrical closing from the control switch and cause unnecessary energizing of the closing mechanism.

Figure 5 is a three-pole, double-throw disconnect switch having an electrical interlock attached to the mechanism. Normally the plunger locks in a cam and prevents operation of the disconnect. A set of coils will permit raising the plunger when conditions are such that the coils can be energized and the disconnect operated.

A set of potential transformers on a drawout carriage is shown in Figure 6. The linkage between the door and the carriage is such that when the door is open sufficiently to get at the potential transformer fuses, the disconnecting contacts from the transformers to the live bus is of sufficient distance to permit the operator to remove the fuses safely.

Figure 7 shows an interlock which prevents connecting or disconnecting a breaker in structure, unless the breaker is open. This is accomplished by an arm having a roller. When the roller is moved out the breaker is tripped free, making it impossible to close the contacts of the breaker in this position. The roller travels on a cam, which permits the roller to be in its normal position only when it is fully connected or disconnected.

With a basic understanding, it is possible to select interlock schemes that can be designed into safe and practical interlocks. Mechanical, electrical, and key interlocks permit innumerable interlock systems to be applied to metal-clad switchgear to provide safety, protection to equipment, or prevent improper operation to processes and production.



MECHANICAL INTERLOCK prevents lowering of breaker unless breaker is in open position. Lowering breaker when it is energized would cause uncontrolled arcing and inflict serious damage on equipment. **(FIGURE 7)**

"ONE FOR THE BOOKS"

Grouting

LEVELING DEVICES IN GROUTING

LEON A. WATTS
Manager, Service and Erection Department
Allis-Chalmers Mfg. Co.

IN GROUTING, like anything else, elementary considerations often assume exaggerated controversial proportion. The advisability or necessity of removing jacks or wedges after grout has set usually stirs more than its share of pro and con opinion.

Heavy equipment needs to be placed on many square feet of grout, instead of being supported on a few points of contact with concentrated loading of 10 tons per quarter square inch, or at the rate of 40 tons per square inch.

Let's assume that a large rotating machine, requiring a grouting area of approximately 5 by 10 feet, is to be placed on a precast foundation of 6 by 12 feet. Also, the machine frame will weigh about 40 tons and is to be aligned, leveled and graded* three inches above the precast concrete base. The frame is also provided with 10 bosses properly located to receive the 10 two-inch foundation bolts. In order to align, level and grade the frame, an adequate number of iron plates, approximately ½, ¾ and 1 inch thick, should be placed under the frame at six locations shown in the accompanying sketch. Grading and leveling with wedges and jack-bolts can be started when the nests of shims are properly spaced and located.

Tightening stops vibration

Assume further that the 40 tons is equally distributed on the six wedges or jack-bolts, each having about ¼ square inch bearing surface area. In spite of this condition, the grout is not yet ready to be placed in the three-inch space between the base of the engine and the roughened and wetted top of the foundation for several reasons.

The machine frame may shift out of level or grade from external vibration if it is not secured to the foundation by tightening the nuts on all foundation bolts as equally as possible, so that each is strained to a load of perhaps two tons. Rechecking the grade and level discloses that the equipment is a fraction out of level, but does not seem serious enough for releveling. Calculations reveal that the tightening of foundation bolts has, in effect, added approximately 20 more tons to the loading on the six ¼ square inch area contacts on the jack-bolts and wedges. Now, the concentrated load on each of the six points of contact is in the order of 10 tons per quarter square inch, or at the rate of approximately 40 tons to the square inch.

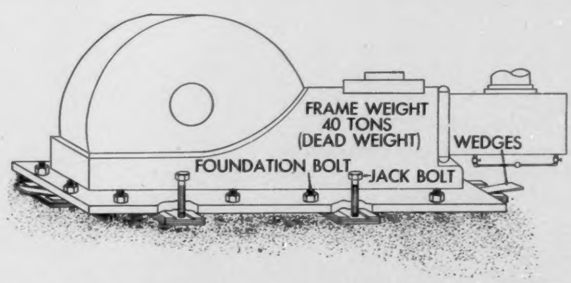
Wedges weaken foundation

Since all of the forms have been readied for grouting, the best preparation of grout is selected. In fact, labor and all other requirements are excellently met. The mixture contains about six gallons of water per sack of cement and is adequately spaded and agitated to provide an excellent, sound, high compression strength grout. Assuming that a week has passed, the installation is still not ready for live load for the simple reason that the frame is still loaded on the knife edge and point contact of the wedges and jack-bolts. It should be understood that gravity grouting, as contrasted with pressure grouting, will not and cannot develop any upward pressure against the machine frame. An operation under these conditions is considered normal when it achieves only 75 percent contact at zero pressure.

True, the equipment will operate satisfactorily if it is left on its present foundation. But, it will operate only until such a time as is required to peen or Brinell the six 10-ton contact points due to load vibration. The dent in the wedge or peen area could well reach a depth of .010 to .050 of an inch. This may be more than the elastic stretch of the foundation bolts. Under this condition, the entire frame is loose and free to move in accordance with the vibration of the unit. Yet, grouting continues to be done in this way.

For best results, remove wedges

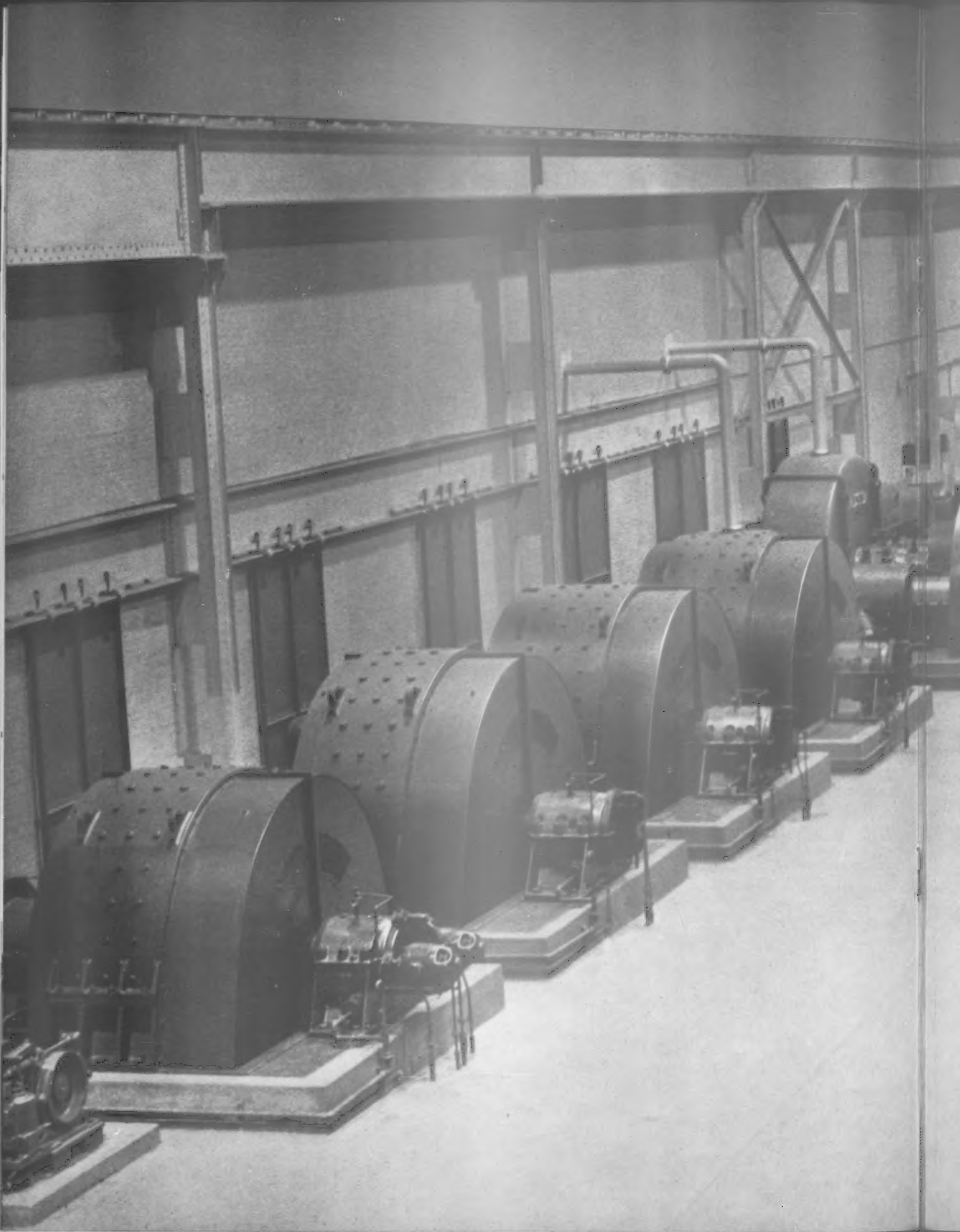
This condition exists because wedges or jack-bolts were not withdrawn. Consider the case where the wedges had been removed or jack-bolts had been backed off. In such a case, the machine will not rest its 60 tons on six contact points, but will

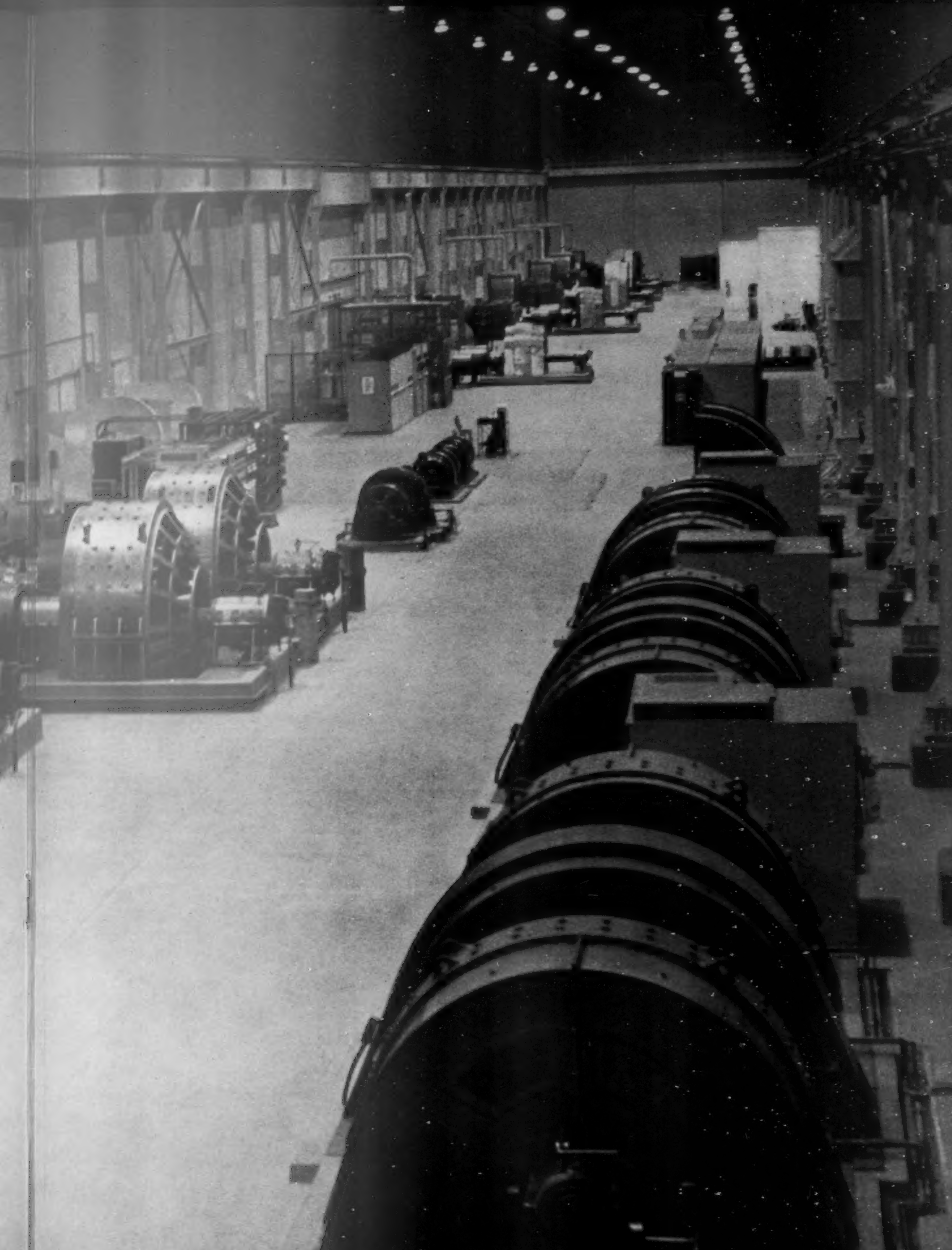


be uniformly distributed over the contact surface. If the grouting had set a week before wedges are removed and jack-bolts backed off, foundation bolts can be checked for tightness. With this check, the bed plate is held firmly against the grout area in contact with no chance to work free, as would be the case when the plate would be riding on the small area on the wedges or points of the jack-bolts. In the first case of riding on the wedges the rate is 40 tons to the square inch, while with the wedges removed the load is distributed to 16 or 17 pounds to the square inch. The latter is nominal loading and, in addition, adds weight of the foundation to the unit, all of which stabilizes the equipment. This hypothetical case, based on actual grouting data, indicates that the best results can be obtained only by removing wedges and jack-bolts.

*Grade, as used in this instance, refers to elevation, with respect to a bench mark or relation to other equipment.

POWER FOR STEEL today. A far cry from steel mills of a few years ago, this well-lighted, spacious motor room powers all main roll drives and supplies a large portion of auxiliary power for a new 68-inch hot strip mill in the east. D-C finishing stand motors, supporting motor-generator sets, d-c control board, roughing train synchronous motors, 450-kw exciter set, and rectifiers were installed recently to increase the supply of vitally needed steel for construction and various production industries.





Fundamentals of AC

PART III OF V PARTS

DR. ERWIN SALZER
Consulting Engineer
Allis-Chalmers Mfg. Co.
Boston, Mass.

Transient recovery voltage poses problems for system and circuit breaker designers.

IN Part Two of this article we began a consideration of transient phenomena in electric systems and their effects upon the conditions under which interrupting devices must perform. We introduced the short-circuit current, the first of the twin problem children of circuit interruption, and one which makes itself evident by upsetting the initial steady state of the circuit while imposing severe thermal and electromagnetic effects on circuit and interrupting device alike.

We will now meet the second, and often just as mischievous, twin problem child of circuit interruption, the recovery voltage, which is born right after the time of the current zero when the interrupting device is attempting to clear the circuit, and which starts to play its pranks right at the time of its birth.

The term, recovery voltage, is used to designate the voltage impressed by the circuit upon the interrupting device after interruption of the current at or about the time of a natural current zero. The recovery voltage tends to break down the arc gap and re-establish the arc.

Simplifying recovery voltage

For the purpose of simplifying an analysis of recovery voltage, it may be assumed that the contact members of a switch or circuit breaker part very rapidly exactly at the time of a natural zero of the current wave. This implies that no arc is being drawn between the contact members, since the current is zero at the instant of contact separation. Assuming further that no electric breakdown will occur between the contact members after their separation, it is possible to consider a completely arcless interruption of a circuit. It must, of course, be kept in mind that perfect synchronization of contact separation with a zero of the current wave, and hence perfectly arcless circuit interruption, cannot actually be achieved, particularly where the mass of the movable contact members is large.

Electric systems form oscillatory circuits capable of oscillating at their natural frequency. Interruption of such a circuit by an interrupting device may cause generation of oscillations having the natural frequency of the circuit, somewhat similar to those oscillations which occur in a water pipe when the flow of water is suddenly interrupted. Such oscillations affect the recovery voltage, and, when taken into account, make an analysis of recovery voltage slightly more complex. In order to simplify matters to the utmost, we may at first neglect the oscillatory properties of the circuit in addition to assuming that arcless interruption occurs at a natural zero of the current wave. Under such hypothetical conditions after current zero, only the normal circuit voltage of the system will be impressed across the gap formed between the separated contact members. That voltage, referred to as the normal frequency recovery voltage, is a first approximation to the recovery voltage which actually appears across the separated contact members of a switch or circuit breaker.

Phase angle affects recovery voltage

Figure 1 shows related current and voltage waves in an electric circuit wherein the current is symmetrical. Here there is a phase angle δ between the voltage V and the current I. Natural current zeros occur at times T_1 and T_2. The instantaneous values of the normal frequency recovery voltages that would appear across the gap formed between the separated contact members if interruption occurred at one of these zeros are T_1X_1 and T_2X_2, respectively. T_1X_1 and T_2X_2 are numerically equal but opposite in sign. Figure 1 clearly shows that the normal frequency recovery voltage depends upon the phase angle between voltage and current. Where the phase angle δ is 90 degrees, the recovery voltage is at its maximum value equal to the peak E_m of the voltage wave, and where the phase angle is zero degrees the recovery voltage is zero.

The relationship between phase angle and recovery voltage is not affected for any given phase angle δ whether the current is lagging, as in the case of magnetizing currents of transformers and induction motors, or leading, as in the case of charging currents of long transmission lines.

The phase angle with which circuit interruption is concerned is, of course, not the steady state constant phase angle which prevails normally in the circuit, but is the transient variable phase angle that prevails in the circuit during the circuit interrupting process.

Normally, short-circuit currents lag the circuit voltage about 90 degrees. Hence the circuit voltage V is at or close to its peak E_m at the time of a natural current zero, and it is thus approximately the peak circuit voltage that tends to break down the gap formed between the separated contact members. Thus the interruption of short-circuit currents may be doubly difficult because of the combination of high current magnitude and a high recovery voltage.

The higher the inductive reactance ωL and resistance R in a circuit, the lower the magnitude of short-circuit currents. On the other hand, the lower the ratio of inductive reactance ωL to resistance R, the smaller the phase angle δ between voltage V and current I, and the lower the instantaneous value of the normal frequency recovery voltage. Such conditions make it easier for a circuit breaker to clear a short-circuit.

Circuit Interruption

Favorable conditions of this kind will be encountered where a short-circuit occurs in a power system at a point remote from a generating station or substation.

Effect of current asymmetry upon normal frequency recovery voltage

Figure 2 shows related current and voltage waves, the current being asymmetrical, that might occur in a short-circuited system in which the short-circuit is initiated at a point of time other than that of peak voltage.

According to Figure 2, the recovery voltage T_1X_1 at the time T_1 of a natural current zero, following a major current loop, is larger than the recovery voltage T_2X_2 at the time T_2 of a natural current zero, following a minor current loop. More generally speaking, where the short-circuit current is asymmetrical, the recovery voltage depends upon the degree of asymmetry of the short-circuit current wave and upon whether the time following a major current loop, or a minor current loop, is being considered.

Transient recovery voltage

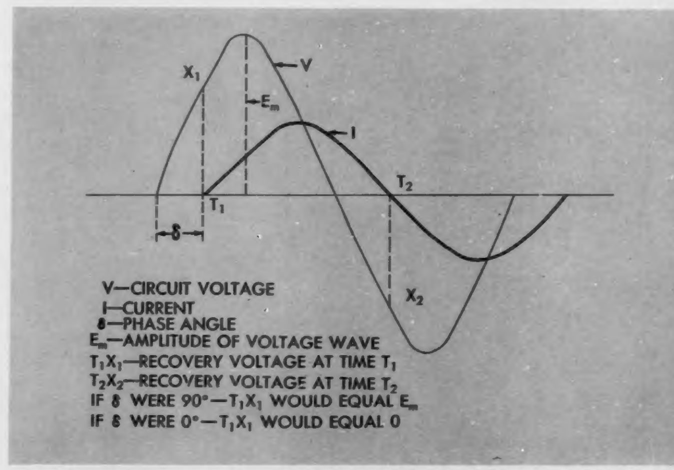
In the simplified cases shown in Figures 1 and 2, the recovery voltage is equal to the normal circuit voltage of the system at and after the time of a natural zero of the current wave at which an interruption of the circuit is attempted or a final interruption of the circuit is achieved. The voltage which is actually impressed across the separated contact members immediately after a current zero differs, however, more or less from the normal circuit voltage. The voltage actually impressed across the contact gap is known as the transient recovery voltage, and is equal to the algebraic sum of the normal frequency recovery voltage (or normal circuit voltage) and a transient component which dies out with time. The transient component of the transient recovery voltage is due to the occurrence, in an inductive a-c circuit when it is interrupted, of a damped periodic condenser charge and discharge.

Figures 3(a) and 3(b) show how the transient recovery voltage is generated by the opening of a circuit by a breaker after a solid line-to-ground fault.

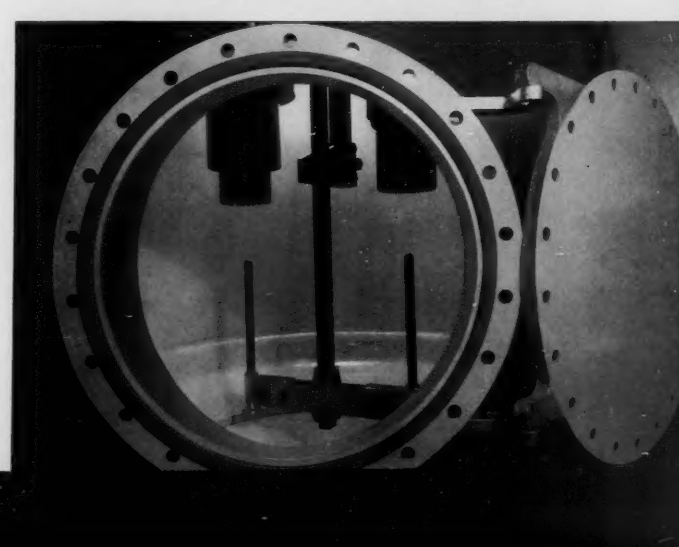
Figure 3(a) shows an electric circuit comprising a source of current (generator or transformer), a circuit breaker CB and a feeder. Figure 3(b) shows the equivalent circuit.

The fault occurs at a point S along the feeder and it is assumed, as before, that the breaker CB interrupts the fault current exactly at a natural current zero, without formation of an arc between its separated contact members. C represents the capacitance of the system (capacitance of the circuit breaker bushings and distributed capacitance). As long as C is solidly short-circuited by CB and by S, no voltage can appear across C. After a certain time following interruption of the circuit by opening of CB, the normal circuit voltage will again prevail across C. A transient voltage will occur across C in the interval between cessation of the short-circuit across C and establishment of final steady state open circuit conditions. The voltage across the separated contact members of CB is equal to the voltage across C as long as the pole of CB at the faulted end of the feeder is solidly grounded by S.

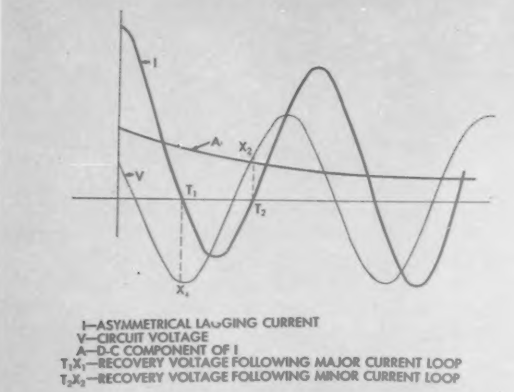
Capacitance C will be charged through inductance L by the source of current (generator or transformer) beginning at the time when, owing to opening of CB, C is no longer shunted by CB and S. Generally L and C form an oscillatory circuit and, therefore, periodic discharges and recharges of C will take place after C has been initially charged. The amplitudes of the voltage at which these oscillations occur overshoot the normal circuit voltage. Neglecting losses in the system, the maximum amplitudes of these oscillations, i.e. of the transient recovery voltage, would rise to twice the peak value of the generator or transformer voltage, but, because of circuit losses, the actual amplitudes are smaller.



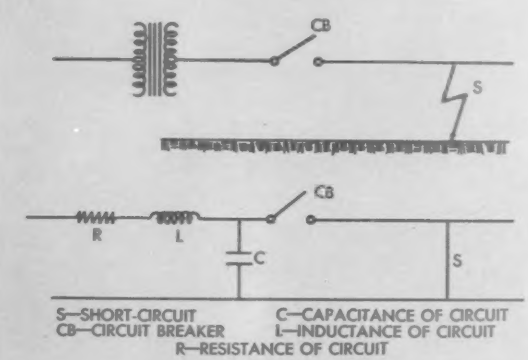
RELATED CURRENT and voltage waves in circuit wherein current is symmetrical illustrate the fact that the normal frequency recovery voltage depends upon phase angle between voltage and current. **(FIGURE 1)**



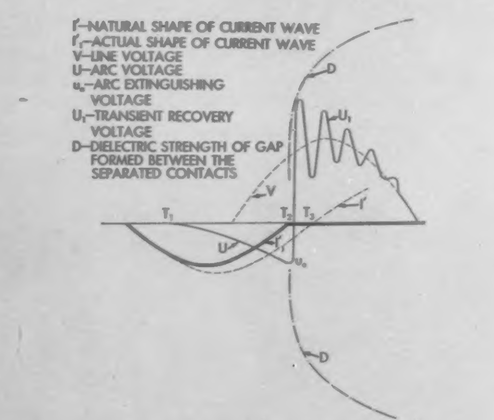
TURBO-RUPTOR arc interrupting devices, seen through the manhole of one pole unit of a 115-kv, 3,500,000-kva, high speed oil circuit breaker. These devices are typical of the class used on high voltage transmission lines where high rates of rise of recovery voltage are encountered.



RELATED CURRENT and voltage waves illustrate the effect of current asymmetry upon normal frequency voltage. **(FIGURE 2)**



LINE DIAGRAM illustrating the clearing of a short-circuit by opening of circuit by a circuit breaker. **(FIGURE 3)**



ARC FORMATION and its effect on transient recovery voltage is depicted in the above diagram. **(FIGURE 4)**

Frequency and damping of transient recovery voltage

The frequency of the transient recovery voltage oscillations is the natural frequency of the system

$$f_n = \frac{1}{2\pi\sqrt{L \cdot C}} \qquad \text{Eq. 1}$$

The natural frequency f_n of an electric system varies within wide limits and is generally high compared to the normal 60 cycles. Since the natural frequency f_n of a system is determined by its inductance L and capacitance C, and since L is largely determined by the Kva generating capacity, and C by the system length, the natural frequency f_n depends upon these factors. Low natural frequencies f_n are in the order of hundreds and high natural frequencies in the order of many thousands of cycles per second. Where the capacitance C of the oscillatory system is relatively small, its natural frequency f_n may be in the order of ten thousands of cycles per second. High recovery voltage frequencies entail a rapid voltage rise or, in other words, more difficult interrupting conditions. Low frequencies of recovery voltage entail a slow voltage rise and an easier interrupting task. Cable systems and long distance high voltage transmission lines involve large capacitances C and their natural frequencies f_n tend to be relatively low, e.g. in the range of hundreds of cycles per second.

Because the oscillations of an electric system at its natural frequency f_n are high frequency oscillations, the times during which the peak values of the voltages are impressed upon an interrupting device are extremely short. Fortunately there is much less likelihood that a gap will break down under a given electric stress, if the duration of the stress is extremely short, i.e. less than half a cycle of a high frequency oscillation.

An electric system may have more than one natural frequency, in which case the transient recovery voltage may be determined by superposition upon the normal frequency system voltage of a number of components, each of which corresponds to one of the natural frequencies of the system.

Any circuit has a certain amount of resistance R tending more or less to dampen oscillations which occur in the circuit. The larger the amount of resistance R in a given circuit, the greater the damping of any oscillation which occurs in it. As long as

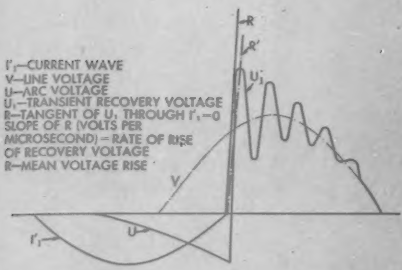
$$R \text{ is less than } 2\sqrt{\frac{L}{C}}$$

the circuit will still be oscillatory. But where sufficient resistance can be inserted into a circuit so as to make R greater than the above factor, the circuit becomes aperiodic and high frequency oscillations will be entirely suppressed. Hence, the damping of transient recovery voltage oscillations will be the more effective, the more resistance is present in or is introduced into the circuit during the interrupting process.

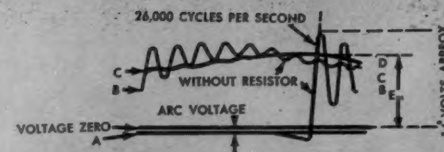
Effect of arc on transient recovery voltage

The foregoing analysis of transient recovery voltage in connection with Figures 3(a) and 3(b) was based on the assumption that the circuit was interrupted at a natural current zero without formation of an arc between the breaker contact members. It is now necessary to consider the effect of the formation of an arc between the contact members upon the transient recovery voltage.

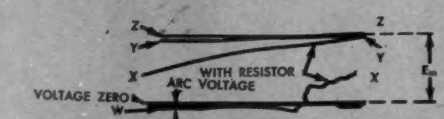
In Figure 4 the line I' indicates the natural shape of a



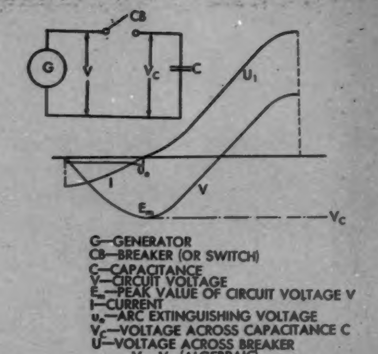
RATE OF RISE of transient recovery voltage expressed by slope of tangent of transient recovery voltage curve at time of arc extinction. (FIG. 5)



CATHODE RAY oscillogram of transient recovery voltage oscillation of 26,000 cycles per second is shown above. (FIGURE 6a)



CATHODE RAY oscillogram of transient recovery voltage with resistor inserted into the circuit showing reduction in rate of rise. (FIGURE 6b)



DRAWINGS show pure a-c capacitive circuit and normal frequency recovery voltage occurring when such circuit is being interrupted. (FIGURE 7)

current wave, i.e. the sinusoidal shape which that wave would have if not affected by the process of circuit interruption. The contacts begin to part at T_1 and, therefore, the arc voltage characteristic U begins to appear at that point. The resistance of the arc is responsible for a certain decrease of the current, i.e. for the fact that the current wave assumes the shape I'_1, rather than retaining its natural shape I'. Because of this, current zero occurs somewhat sooner in point of time, i.e. at T_2 rather than at T_3. As the amount of contact separation increases, arc elongation and other deionizing effects increase, and the resistance of the arc increases with the arc voltage increasing in proportion. At T_2 the arc voltage has reached the largest value it can reach, i.e. the extinguishing voltage u_e. At that point of time the arc current drops to zero and the arc vanishes. The high frequency transient recovery voltage, the determining factors of which were just analyzed, starts from the point of maximum arc voltage, i.e. arc extinguishing voltage u_e. After passing through zero, this transient voltage increases to its peak value and thereafter oscillates about the normal system voltage V wave form. The transient recovery voltage U_1 tends to cause re-establishment of the arc after current zero, and will actually effect such re-establishment, if sufficiently high.

Criterion of interruption

The dielectric strength of the arc gap may be measured by the voltage which must be applied across the contact members to break down the gap. At T_2 this voltage is equal to the arc extinguishing voltage. It then rises, first extremely rapidly, and thereafter at a relatively lower rate. The two lines D indicate the rise of the dielectric strength of the arc gap versus time in terms of breakdown voltage. Since the dielectric strength of the arc gap is a property which does not depend upon the direction of the voltage, the curves D appear on both sides of the axis of abscissa.

Obviously, circuit interruption will be completed if the entire recovery voltage line U_1 lies within the two dielectric recovery lines D. Should an ordinate of recovery voltage line U_1 at any point of time be equal to an ordinate of dielectric recovery line D, re-establishment of the arc will occur.

Rate of rise of recovery voltage

It will be obvious from Figure 4 that had the recovery voltage U_1 risen to the same peak amplitude at a more rapid rate it would have intersected the curve D of the dielectric strength of the arc gap, and arc reignition would have occurred. In general, *the rate of rise of the recovery voltage is of even greater significance in circuit interruption than the peak voltage to which it rises.* Hence it is a widely accepted practice to use the rate of rise of the recovery voltage immediately following current zero, expressed in terms of volts per microsecond, as an indication of the severity of prevailing transient recovery voltage conditions.

The rate of rise of the transient recovery voltage is generally defined as the slope of a straight line passing through zero voltage at the instant of arc current zero and thence through the front salient or another peak of the curve describing the transient recovery voltage. Or the rate of rise of the transient recovery voltage may be defined as the slope of the steepest line which can be drawn from the point of voltage zero at the time of arc current zero to any point of the recovery voltage oscillations. A line defining the rate of rise of the recovery voltage is shown in Figure 5 and indicated by the letter R. Sometimes reference is made to the mean voltage rise which is indicated in Figure 5 by dotted line R'.

The rates of rise of recovery voltages encountered in circuit interrupting practice vary within wide limits. High voltage power circuit breakers must be able to cope with recovery voltage rates of the order of kilovolts per microsecond.

Use of cathode ray oscillograph for investigating transient recovery voltage

The preceding illustrations of the transient recovery voltage are entirely diagrammatic and, for the sake of clarity, oscillations were shown occurring at the natural frequency f_n, only a few times higher than the 60 cycle system frequency. As previously stated, much higher natural frequencies f_n are actually encountered. Generally, the frequency of the transient recovery voltage is so high that a satisfactory record can only be obtained with a cathode ray oscillograph. Figures 6(a) and 6(b) are line drawings obtained by retracing cathode ray oscillograms. The first mentioned figure refers to a circuit breaker having no particular means for limiting the transient recovery voltage while the last mentioned figure refers to a circuit breaker provided with means for inserting resistance into the circuit during the process of interruption for limiting the transient recovery voltage.

In order to obtain a clear oscillographic record, it may be necessary to sweep the cathode ray beam across the screen of the oscillograph at such speed that the end of the screen may be reached long before the transient recovery voltage

wave has died out. In such cases, the entire phenomenon may be recorded by resorting to sweep circuits by means of which the cathode ray beam, upon reaching the end of the screen, is immediately retransferred to its point of origin and thereupon proceeds to record the phenomenon in the same way as during its first sweep. This process may repeat itself several times. When evaluating a cathode ray oscillogram which has been made with a cathode ray oscillograph of that kind, the portions of the record must be considered in the sequence in which they were recorded.

For instance, referring to Figure 6(a) which shows a transient with a frequency of 26,000 cycles per second, the record starts at A, continues to B (right side), restarts at B (left side), continues to C (right side), restarts at C (left side) and terminates at D. This oscillogram shows the arc voltage to be substantially constant during the half cycle, at the end of which the circuit is interrupted. Towards the end of the half cycle the voltage rises to the arc extinguishing voltage and at that point the high-frequency transient appears. The peak value of that transient is about 1¼ times the value of the peak sinusoidal line voltage E_m. The oscillations decrease gradually to C where the transient is almost zero. Final steady state conditions are reached somewhere between C and D.

The record according to Figure 6(b) starts at W. The geometry of the arc voltage is similar to that shown in Figure 6(a). Owing to the insertion of a resistor into the circuit during the process of interruption the rise of the transient recovery voltage is greatly reduced. The record which starts at W continues to X (right side), restarts at X (left side), continues to Y (right side), restarts at Y (left side) and continues to Z (right side). The last sections of the record correspond to the sinusoidal line voltage which is not exceeded at any time by the transient recovery voltage.

Switching voltage surges

The term switching voltage surge refers to any overvoltage caused, or initiated, by a switching operation. Sometimes that term implies that the magnitude of the voltage exceeds considerably the normal voltage of the system.

Surge voltages may result from various different causes. One of them is intermittent arcing. In case of intermittent arcing, the circuit is interrupted each time the arc is extinguished and reclosed again each time the arc restrikes. The theory of cumulative voltage build-up by intermittent arcing, which will shortly be outlined below, shows how various surge voltages may be generated by periodic opening of a circuit on account of arc extinction and reclosing of a circuit on account of restriking of the arc. The magnitude of the surge voltage which may be built up by intermittent arcing depends upon the points of time at which arc extinction and restriking take place. An arc may be extinguished close to a natural zero of the fundamental current wave or close to a natural zero of an oscillatory high frequency current due to the presence of inductance L and capacitance C in the circuit. An arc may restrike close to the crest of the fundamental frequency system voltage or close to the voltage crest of a high frequency oscillatory condenser charge and discharge. If consecutive restrikings occurred at certain predeterminable intervals at certain points in the voltage, surge voltages would theoretically pyramid and reach high magnitudes. Fortunately, the surge voltages actually realized on account of intermittent arcing are much less than the theoretical maximum because conditions for cumulative build-up of maximum surge voltages do not obtain in practice.

Restriking phenomena and the attendant voltage surges are encouraged when switching capacitive currents encountered when de-energizing long transmission lines, underground cables and large capacitor banks such as used for power factor correction.

The case of interruption of capacitive circuits is of sufficient practical importance to warrant particular consideration of it.

Interruption of capacitive circuits

Figure 7(a) is a diagram of a pure capacitance circuit, and Figure 7(b) illustrates the process of interruption in such a circuit.

At the time the current I becomes zero, the voltage V lagging the current I by 90° reaches its peak value E_m. The capacitance C is then charged to the voltage V_c equal to the circuit voltage V minus the extinguishing voltage u_e of the arc. Assuming the extinguishing voltage u_e to be negligibly small compared to the peak value E_m of the circuit voltage V, the voltage V_c to which the capacitance C is charged at the time of current zero may then be considered equal to the peak value E_m of the circuit voltage.

The voltage U_1 which tends to break down the arc gap in the circuit breaker CB is equal to the algebraic difference between circuit voltage V and the voltage V_c to which the capacitance C is charged. At the instant of current zero the voltage U_1 across the contact members of the circuit breaker CB is zero. Voltage U_1 will rise within half a cycle to twice the peak value E_m of the circuit voltage V. This is a relatively slow rate of rise and usually affords ample time for deionization of the arc gap before a relatively high voltage, in the range of two times E_m, is impressed upon it. At low kilovolt-amperes the deionization of the arc gap tends to be sufficient to withstand twice the peak value E_m of the circuit voltage V, but this may not be the case at higher kilovolt-amperes. If the arc gap breaks down under the electric stress to which it is subjected, i.e. the arc restrikes, and there is inductance in the circuit, the mechanism of cumulative voltage build-up gets under way.

Cumulative voltage build-up after restriking

Figures 8(a) and 8(d) tell the same story as Figures 7(a) and 7(b), but add to it one of the several possibilities that may occur if the arc restrikes at the peak value of U_1. Figure 8(a) is a simplified diagram of the circuit under consideration and shows the inductance L, the circuit breaker CB, the capacitance C_1 and the capacitance C_2, and the feeder line F. Figure 8(b) shows the current I in the circuit plotted versus time. Figure 8(c) shows the voltage V_{c1} across capacitance C_1 and the voltage V_{c2} across capacitance C_2, while Figure 8(d) shows the voltage U_1 across the contacts of circuit breaker CB.

Initial steady state conditions prevail in the circuit until T_1 when the circuit is interrupted at a natural zero of the steady state capacitor current I. Assuming the capacitor current I remains interrupted until T_2. Then line F (capacitance C_1) remains charged in the interval T_1-T_2 at substantially the potential it had at T_1, which is close to the peak value E_m of the circuit voltage. Hence the voltage U_1 across

the contact members of circuit breaker CB is built up to about twice the value of E_m, as more fully set forth in connection with Figure 7(b) and also shown in Figure 8(d).

At T_2 the arc restrikes across the separated contacts of circuit breaker CB, resulting in an equalizing current I_e. That equalizing current is a high frequency current having a frequency f_1 determined by the inductance L and the sum of capacitances C_1 and C_2. Final interruption of the circuit may or may not be effected at the time T_3 when the first zero of equalizing current I_e occurs. Figures 8(b) to 8(d) have been drawn under the assumption that final interruption of the circuit takes place at T_3 after the equalizing current I_e lasted but half a cycle of the oscillation at the frequency f_1.

The voltages acting in the circuit at T_2 are the peak value $+E_m$ of the circuit voltage V and the voltage to which capacitance C_1 is charged, which is approximately $-E_m$. This difference of potential of 2 E_m is responsible for initiation of equalizing current I_e. Current I_e readjusts the voltage V_{c1} across capacitance C_1 toward the peak $+E_m$ of circuit voltage V. However, on account of inductance L voltage V_{c1} overshoots its mark $+E_m$ by the initial potential difference $2E_m$. Theoretically V_{c1} would rise to $+3E_m$ but actually it will be smaller on account of damping. In Figure 8(b) the peak of the oscillatron V_{c1} is shown to lie somewhere between $+2E_m$ and $+3E_m$. After T_3 the line F will retain substantially the voltage V_{c1} it has at T_3.

Between T_2 and T_3 the voltage V_{c2} across Capacitor C_2 and the voltage V_{c1} across capacitor C_1 are about the same, since both capacitors are conductively interconnected by the low resistance arc in CB. At T_3 that arc is being extinguished and the arc gap converted into an insulator; hence the voltage V_{c2} across capacitor C_2 will start to deviate markedly at that point of time from the voltage V_{c1} across capacitor C_1. The voltage V_{c2} across capacitor C_2 will be the sum of a high frequency oscillation at a frequency f_2 and the normal circuit voltage V. Frequency f_2 is determined by the inductance L and the capacitance C_2.

As shown in Figure 8(d), the voltage U_1 across the contacts of circuit breaker CB is nearly $2E_m$ at T_2 and then breaks down to arc voltage u_e values which prevail during the interval T_2-T_3. It was assumed in drawing Figure 8(d) that the length of the arc gap is small and the arc voltage u_e insignificant. The recovery voltage U_2 that appears at 3 across the separated contact members of the circuit breaker CB is a transient equal to the algebraic difference of voltage V_{c2} and voltage V_{c1} and in the case shown reaches a peak value of more than $-3E_m$.

It has been assumed above that the capacitances in the circuit are lumped capacitances, which is quite true, when considering de-energizing of large static capacitor banks or short lengths of high-voltage cables. Slightly different yet similar considerations apply to the case of distributed capacitance for which switching of long unloaded transmission lines or cables is representative.

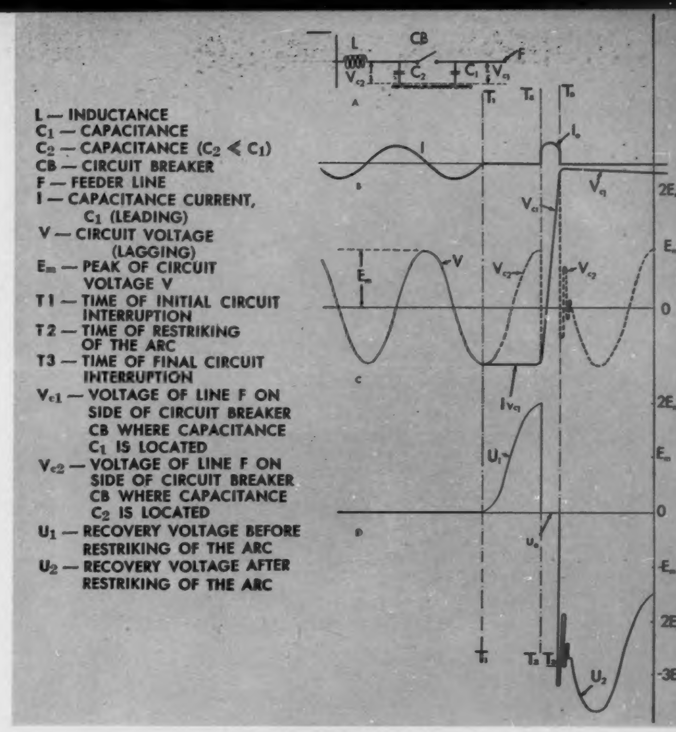
Conclusions

The major problems in the design and development of switches and circuit breakers arise out of high currents and out of high voltages. The highest interrupting currents are generally encountered where there is a large concentration of power in a generating station and power house circuit breakers are called upon to interrupt short-circuit currents at moderately high voltages. The highest voltages and recovery voltage rates are generally encountered where circuit breakers are called upon to control long distance transmission lines operated at ultra-high voltages. It is fortunate that not one and the same type of apparatus is required to cope with both extremely high currents and extremely high voltages. This makes it possible for design and development engineers to concentrate in each particular application on the more predominant factor, either ability to handle extremely high currents, or ability to handle extremely high voltages and recovery voltage rates.

There is no difficulty in assessing a value for severity of interruption in terms of interrupting current. The matter is more difficult when it comes to assessing a value for severity in terms of recovery voltage. Recovery voltage may be described in terms of natural frequency of the circuit or in terms of rate of rise in volts per microsecond, but neither of these specifications is complete, each lacking any information relative to the peak to which the recovery voltage may rise.

The shape of the recovery voltage curve is primarily a circuit characteristic, depending upon the constants of the circuit; but it also depends upon the way in which the arc path between the separated contact members of the interrupting device is being deionized and gap insulation built up.

A good deal of the progress achieved in recent years in mechanical, chemical and electrical engineering may be attributed to the fact that the old feud between empiricism and theory has been finally arbitrated. An alliance between both was formed, resulting in widespread engineering progress. Progress recently achieved in the applied science of circuit interruption on account of that new alliance is so considerable that it has hardly been surpassed by progress in any other field.



CUMULATIVE VOLTAGE build-up after arc restrikes is shown above. Capacitances in the circuit are assumed to be lumped capacitances. **(FIG. 8)**

In the next part of this article Dr. Salzer will begin a discussion of the Design Principles of Circuit Interruption.

POTHEADS *are important, too!*

H. H. ACKMANN
Switchgear Sales
Allis-Chalmers Mfg. Co.

Choice of cable termination influenced by operating needs, climate and location

CABLES and their terminations, for some unexplained reason, seem to be set apart from the usual electrical equipment. Yet they are as vital to efficient and economical power distribution as the major pieces of equipment they service. The tendency to underestimate their value often results in mistakes made in coordinating electrical equipment with the physical structure of the building in which it is installed, and with the conduits and cables connecting electrical equipment.

Cables first used on telephone lines

The origin of power cables and their terminations must be known before this problem can be truly understood and appreciated. Cables were first introduced for telephone circuits. Shortly after the telephone was accepted as a practical means of communication, telephone engineers realized that poles were carrying numbers of lines beyond their physical and economical limit. The congestion was relieved by insulating each conductor with a paper covering and then enclosing a large number of conductors within a lead sheath. With this development, cables could be pulled through conduit underground as well as hung from a steel cable on ordinary telephone poles which, heretofore, had been carrying the aerial bare copper conductor.

Paper insulated conductors solved the problem of congestion only. Another difficulty appeared—that of moisture seeping into the paper insulation under the lead sheath. Telephone engineers devised paraffin-filled splice joints and sealed the ends of cables with a cast iron pot which was wiped on to the lead sheath and filled with paraffin. This, in effect, was the beginning of cable termination and the origin of the term "pothead."

Power cable termination followed

Power cables followed telephone cables by several years, since power consumption was small and the number of consumers did not necessarily dictate the number of conductors. Although power distribution engineers were faced with a similar problem, they had the knowledge and experience of telephone engineers at their disposal.

In time, however, power distribution systems in large cities required larger conductors. Consequently, overhead space became costly. Power utilities, too, realized the economic advantage of installing conductors underground. Since no other cables were available at that time, power companies turned to manufacturers of telephone cables for their supply.

The inadequacy of the original cables to meet power requirements became apparent almost immediately. Since the voltage impressed on the conductors of power cables was greater than that of telephone circuits, the moisture problem was even more acutely felt. Consequent experiments to overcome this difficulty revealed that paper was an excellent dielectric when treated with oil. The discovery was so conclusive that to this day high voltage cables (Figure 1) are still, to a large extent, paper insulated.

However, the use of oil as an impregnating solution for the paper only complicated matters for users of power cables, for unless the lead sheath was completely sealed at both ends and at the splices the cable oil would run out and air with moisture would seep in. Consequently, the dielectric strength of the paper insulation was reduced until a flashover occurred either between phases or between conductors and the lead sheath. Thus, the terminating schemes used by telephone engineers were inadequate for the electrical engineer's needs, and a new and better method of terminating had to be developed.

First termination of power cables

Basically, the first potheads designed for power cables were the same as the terminals used for telephone circuits with one exception—the addition of a cast iron cover in which porcelain bushings or insulators were cemented. The conductor, with its insulation, was pulled through the porcelain bushing which, in addition to serving as a mechanical support for the conductor, provided a suitable base for building a tape cone for sealing the top of the pothead.

A heavy compound, similar to common roofing tar, was used to fill the pothead. Because it remained hard in almost all weather conditions and retained the oil in the cable, the new pothead solved immediate power distribution needs.

This hard compound remained in use for about 20 years, until gradually increasing voltages bred new difficulties. Moisture trouble appeared when voltages increased. Insulating compounds used to fill potheads became hard and brittle during freezing weather. An internal flashover would occur when a disturbance on the system caused a surge in voltage because shrinkage cracks had formed in the compound in such a way that the internal creepage distance had been lowered to a dangerous point.

As long as these hard compounds were used, pothead construction of that period permitted the use of cork or

fibre gaskets even though gaskets hardened and retained a permanent set. Higher voltages also brought about the use of oils and softer compounds, such as petrolatum, which the cork and fibre gaskets could not retain. Oils and softer compounds, however, possessed large coefficient of expansion. Because of this property, additional provisions were required to overcome undue expansion. One of the major developments was the location of pressure oil tanks at the ends and at some of the splices of oil-filled cables (Figure 2) for maintaining constant pressure.

Except on high voltage cables (15 kv and up), cost of these expansion provisions was prohibitive. This disadvantage was somewhat overcome by the development of an insulating compound which would not shrink or crack in cold weather, but which was considerably harder than the oils and soft compounds that had been introduced. This compound, although not as easy to hold as the harder compound, simplified the gasket problem. The improved gaskets used in today's potheads do not set in a year or two, as previously, but retain their resiliency under adverse weather conditions for several years. Consequently, the oil impregnated cable can be terminated in a modern pothead with little danger of oils or compounds escaping through the gaskets.

Gas-filled cable introduced

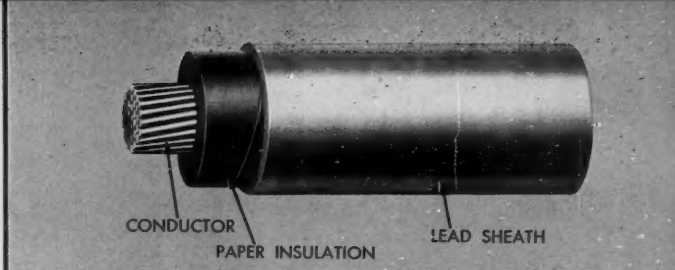
Development of gas-filled cables during the past 10 years posed another problem for designers of potheads. In essence, it is a paper insulated cable with a passage through the insulation for nitrogen gas, which fills any voids that may be present in the insulation. In construction it is much like the oil-filled paper insulated cable except that oil is drained and cable is filled with nitrogen. Its main advantage is that a positive pressure is maintained within the cable to prevent moisture seepage whenever the lead sheath cracks or a leak occurs. Should anything occur which would cause pressure within the cable to diminish, an alarm indicates the existence of a defect, providing sufficient time to locate and repair damage before the cable fails.

About the time that the gas-filled cable was introduced, ceramic engineers devised a new process of metal coating porcelain bushings. A comparatively simple method of soldering porcelain bushings to the metal body of the pothead eliminated all gaskets. This solder-porcelain pothead was first used on gas-filled cables and then applied to oil pressure installations. This simplified improvement found widespread application with considerable numbers of them being used today.

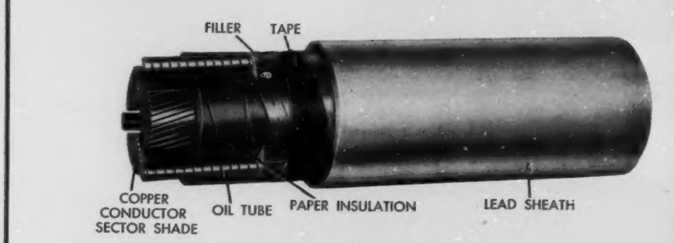
Thus far the discussion has been limited to paper insulated cables since they were the first lead-covered type developed and because paper insulation is the hardest to terminate and splice. The dielectric strength of paper insulation is higher than that of any other material used for cable insulation, making it suitable for application on the higher voltage cables and on the larger conductor sizes. Because of these properties, paper is selected as the most practical insulation for important circuit cables.

Varnished cambric insulated cable

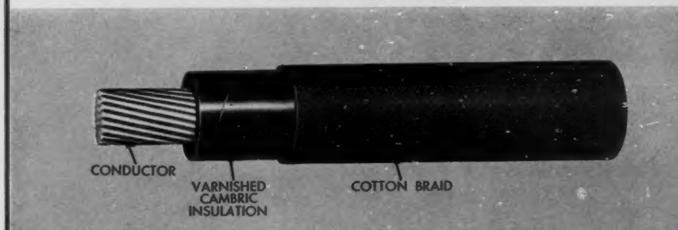
Varnished cambric insulation is probably used more in general power cable (Figures 3, 4 and 5) applications than



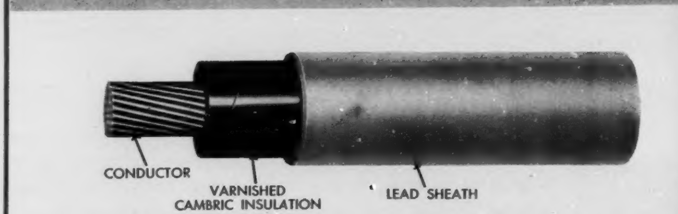
SINGLE-CONDUCTOR paper insulated power cable. (FIGURE 1)



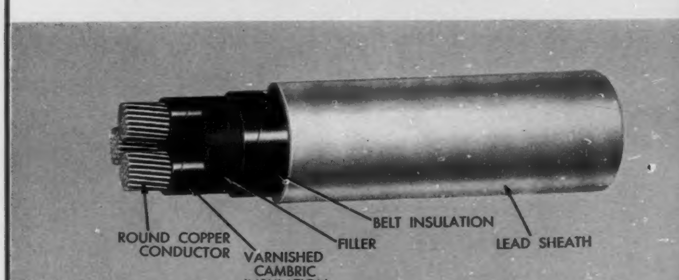
THREE-CONDUCTOR oil-filled paper cable. (FIGURE 2)



SINGLE-CONDUCTOR varnished cambric braided cable. (FIGURE 3)



SINGLE-CONDUCTOR varnished cambric leaded cable. (FIGURE 4)



THREE-CONDUCTOR varnished cambric leaded cable. (FIGURE 5)

THREE-CONDUCTOR rubber insulated and jacketed cable. (FIGURE 6)

POTHEADS preserve cables from air and moisture seepage at their most vulnerable point. The two 3-conductor off-set potheads installed in the rear of a switchgear unit equipped with air blast circuit breakers are only one of a wide variety of terminations.

any other cable insulation on voltages between 2.4 and 15 kv. Since its dielectric strength is less than that of paper, a greater insulation thickness is needed for an equivalent voltage. However, its moisture resistance is greater than that of paper, consequently joints and terminations are much easier to make. Because the cost of varnished cambric insulated cable compares favorably with other cables, it is usually favored for primary distribution voltages.

Rubber insulated cable

Natural rubber has been used as an insulation for copper conductors for the same length of time as any other insulation. Because it is not affected by moisture to any appreciable amount, it was not enclosed in a lead sheath until after varnished cambric and paper insulated lead covered cables were introduced. Lead covering for rubber insulated cables (Figure 6) was applied principally to protect the rubber insulation from possible chemical reaction in the duct line.

Several types of synthetic rubber compounds have been developed in the past ten years as substitutes for natural rubber. Most of them, however, lacked the quality of dielectric strength of the original rubber insulation, although their ability to resist weather, abrasion, and chemical reaction is excellent. Today, various types of rubber-jacketed cables are available, having some good insulating rubber compound around the conductors with a synthetic rubber jacket taking the place of the lead sheath for protecting insulated conductors.

Cable terminations improve

By far, paper insulated cables require more extreme care in protecting them from moisture, regardless of the potential impressed on the conductor, than any other previously discussed cable. Cables insulated with varnished cambric, although not as sensitive to damage by moisture, nevertheless requires protection in the form of potheads for the ends.

For a number of years, potheads were not used to terminate varnished cambric insulated cables, especially on industrial applications. This trend has changed in recent years, due largely to increasing load requirements in larger industrial plants and consequent extensions of cable systems within them.

Another factor which influenced the return of the pothead for terminating varnished cambric insulated cables was the development of lower viscosity cable impregnating compounds. A sealed termination of the pothead type was required to retain the new cable oil or compound in the cable, providing added assurance that cables would perform satisfactorily.

Rubber insulated cables do not require potheads except to protect conductor insulation from the deteriorating effects of weather or chemical action. Cables insulated with rubber or similar synthetic compounds have not been too practical on voltages over 5,000 volts, with the exception of special applications where other than normal conditions exist.

Special types of cables

Usually, cables are installed in conduit, either in the building structure or underground. However, there are three types that should be mentioned in all cable discussions. The first, an aerial cable, is of recent origin. It is suspended from pole to pole and supported by a steel cable. The aerial cable has a rubber compound insulation and does not need a pothead.

The second is a direct burial type, trenchlay. The parkway, another direct burial type, is the third. Both were designed for burying directly in the earth, with provisions for protecting conductors from sharp objects. Both have rubber insulation for the conductors. They differ in that the parkway has a lead sheath while the trenchlay cable has none.

The parkway cable (Figure 7) has a layer of jute over the lead sheath, with two strips of steel tape wound helically over the jute and then covered with an additional layer of tar-impregnated jute on the outside to protect the steel tape from moisture and acids that may be present in the soil. The trenchlay covering is similar to the parkway except that there is no lead sheath and, instead of steel tape, a durable fibre tape is used.

Both the trenchlay and the parkway require some sort of termination. A pothead, using a special entrance fitting specifically designed for such cables, is the most practical and advisable.

Submarine and borehole cables require special applications, too. Since both are of almost similar construction, they can be terminated similarly. The submarine cable (Figure 8) and the borehole cable (Figure 9) are designed for special applications. Their construction consists of any standard lead covered cable which, in turn, is covered with a layer of jute around the lead sheath and a helical wrapping of No. 6 or No. 8 galvanized steel wire wound helically around the cable. A layer of tar provides protection against corrosion. The steel wire contributes mechanical support and protection for the power cable on the inside.

Submarine cables are used for underwater installations, as their name implies. Borehole cables are usually dropped vertically through a borehole to an underground substation likely to be found in mines or other underground installations. Depending upon its length, the borehole may be supported at several points in its drop from the surface of the ground to its termination underground.

Either of these cables requires special treatment for effective termination. Necessary fittings for terminating the wire armor are usually provided with the pothead. The complete cable make-up should be obtained before a particular method of termination is selected. Such precautions apply especially in installations requiring submarine or borehole cables.

Typical cable connections

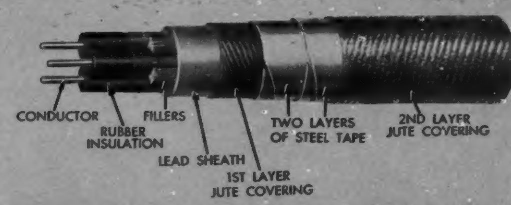
Power cable connections can be made in three ways: a hermetically sealed pothead, an open, compound-filled terminator, or application of some sort of copper terminal lug with a method of clamping or supporting the cable. Conditions and installation requirements determine the type of cable termination to be used.

The most common method of terminating is the hermetically sealed pothead. Termination of this sort has a gasket-sealed copper terminal arranged at the top of the porcelain bushing in such a way that the gasket is held under compression. The copper terminal, with its gasket, holds the compound within the pothead and prevents moisture and air from entering in the event a vacuum develops when the pothead and cables are cold.

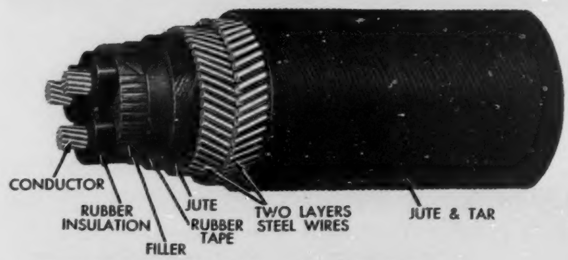
The sealed terminal, or capnut pothead, is available either in the multiple conductor type with a porcelain bushing and terminal for each conductor or with only one porcelain bushing and terminal for use with a single conductor cable. The copper terminal of the capnut type of pothead consists of three parts (Figure 10): internal connector, compression fitting or hoodnut, and an aerial or terminal lug. The internal connector is a copper stud in which the cable conductor is terminated. The hoodnut, or compression fitting, is the external part of the terminal that tightens the gasket against the porcelain bushing to seal the pothead. In order to make a good electrical connection to the terminal, some sort of lug or fitting is usually added to the terminal for terminating the aerial conductor or bus bar. It should be noted that the typical pothead designs were chosen for illustrative purposes only. Potheads used with particular apparatus may vary in construction from those illustrated.

The sealed terminal pothead is generally recommended for paper insulated and varnished cambric insulated cables, particularly on voltages five kv and beyond.

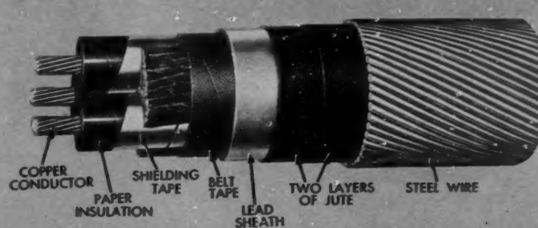
Some cable installations permit cables to be terminated in potheads or terminators which do not have the copper



MULTI-CONDUCTOR rubber insulated parkway cable. **(FIGURE 7)**

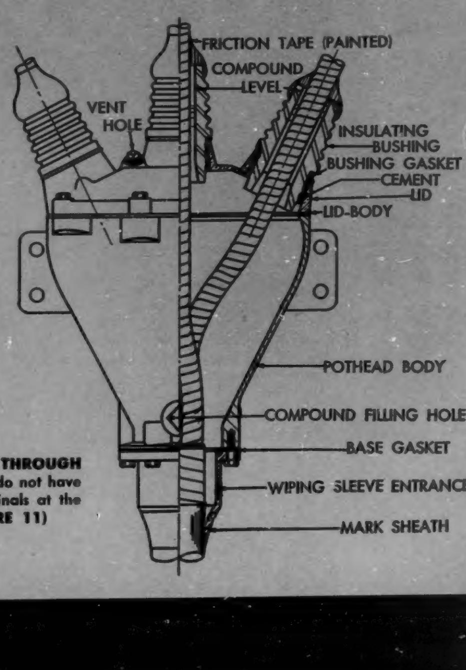


THREE-CONDUCTOR submarine cable. **(FIGURE 8)**



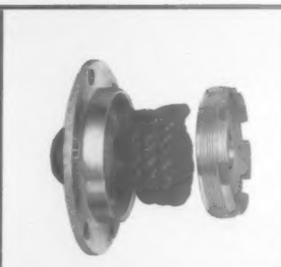
THREE-CONDUCTOR borehole, mine and shaft cable. **(FIGURE 9)**

POTHEAD CAPNUT terminal assembly. **(FIGURE 10)**

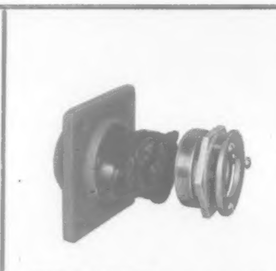


STRAIGHT-THROUGH terminators do not have copper terminals at the top. **(FIGURE 11)**

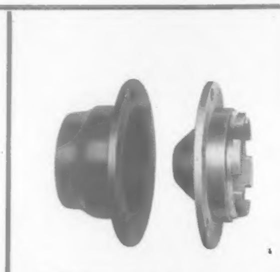
WIPING SLEEVE entrance fitting for pothead is most commonly used. **(FIGURE 12)**



EXPLODED ASSEMBLY view of stuffing box entrance fitting for pothead. **(FIGURE 13)**



SOME FITTINGS are a combination clamping ring and stuffing box entrance. **(FIGURE 14)**



STUFFING BOX entrance fitting and conduit coupling type of termination. **(FIGURE 15)**

terminal at the top of the insulator but, instead, the conductor (Figure 11) with its insulation is drawn directly through the cover or insulator. The copper of the cable is terminated in a terminal lug on the apparatus as if a pothead were not used.

Although more economical, easier to install and, on the whole, satisfactory, potheads with the open or through porcelain bushings are limited to installations utilizing varnished cambric or rubber insulated cables. Even with varnished cambric cables a certain amount of leakage occurs when load conditions create heat in the cables. Another requisite arising from the application of the straight through pothead is that the ends of the cable should be approximately at identical levels, otherwise the compound at the lower level of the pothead will escape while compound at the other extreme will disappear into the cable. Use of softer cable oils in the manufacture of varnished cambric cables during the past 10 years has aggravated the difficulty of retaining cable oils and compounds in the open porcelain bushing pothead.

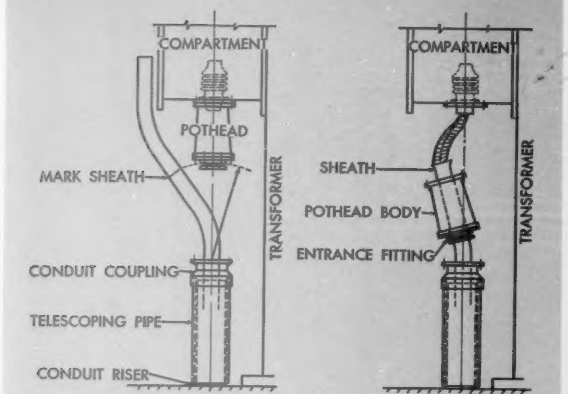
Selecting cable entrance fittings

Final choice of pothead determines the corresponding cable entrance fitting. The several types available can be more or less classified into three categories: wiping sleeve, stuffing box and clamping ring.

The wiping sleeve entrance (Figure 12) is possibly the most commonly used and is considered superior to the other two. Essentially, it consists of a brass cone bolted to the base of the pothead through which the lead cable is drawn. Before the remaining portion of the pothead is built, the lead sheath is removed into the wiping sleeve until only about an inch of lead remains inside the cone. After the pothead is assembled, an ordinary wiped joint is made between the lead sheath and the conical surface of the wiping sleeve. This type of cable entrance is reliable and provides a satisfactory electrical bond and a tight seal at the base of the pothead, providing the wipe is properly made.

The most commonly used mechanical cable entrance is the stuffing box (Figure 13). As its name implies, it consists of two metal parts which tend to compress cord packing tightly against the cable when the bolts or threaded portion on the movable part of the fittings are tightened. Although generally considered satisfactory, the stuffing box develops an occasional leak when used to seal potheads containing soft compounds or oil. Other disadvantages of this type of entrance are that it does not effect a good electrical bond between the lead sheath and the pothead body, nor does it provide dependable mechanical support.

CABLE TERMINATIONS must be protected from animals as well as the effects of the elements. Underground conduits extend above ground in this feeder voltage regulator installation to protect cables from rodents.



SLIP JOINTS in conduits are one of the simplest means of providing required flexibility for alignment and clearance on a pothead installation on electrical equipment. **(FIGURE 16)**

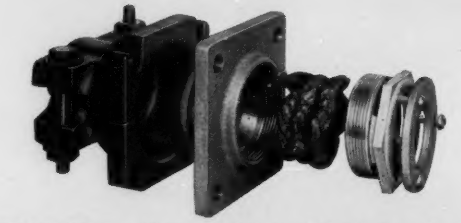
Various methods of clamping have been tried to overcome the disadvantages of the stuffing box. One of the most successful is the clamping ring arrangement where the lead sheath is pulled through one metal ring and then belled over and a second ring is then bolted atop the flared lead sheath. The clamping ring grounds the lead sheath of the cable to the pothead body. Unless the thickness of this lead sheath is uniform, there is a possibility of leakage. One of its advantages is that it definitely provides a mechanical support for the cable.

Commercially available potheads utilize a combination fitting which has the advantages of the clamping ring and still retains the reliability of sealing the base of the pothead at the same time. Known as the combination clamping ring and stuffing box (Figure 14), it consists of a stuffing box in which the lead sheath is not only grounded, but also clamped at the top of the fitting for considerably increased mechanical support. This combination fitting is more retentive than the ordinary stuffing box. The lead sheath is clamped in such a way that it practically seals the cable and relieves pressure on the stuffing box, retaining any compound or oil which may seep past the clamping ring.

Pothead termination of cables requires some sort of cable entrance fitting. Commercially purchased potheads are furnished with either wiping sleeve or stuffing box entrances when cable information is not known, for either of these can be cut in the field by installation personnel. However, when potheads are purchased and complete cable data is known, the correct entrances to fit the particular termination will be supplied with the pothead.

Fitting conduit terminations

Sometimes the manufacturer of a transformer, switchgear or a generator finds that it is necessary to mount a pothead on the end of a conduit run. Such an installation would require a conduit coupling with the pothead in the event that the conduit is to be connected to the pothead. A stuffing box, clamping ring or one of the combination clamping ring and stuffing box entrances (Figure 15) provide the most practical solution. Size of the coupling is determined by the dimensions of the conduit.



DIRECT BURIAL cables can best be terminated in the pothead when a clamping ring and stuffing box entrance and armor clamp are used to seal the base of the pothead. **(FIGURE 17)**

There is one danger in an installation of this type which should be guarded against. When conduit is brought directly to a pothead which, in turn, is rigidly fastened to some other piece of equipment two things must be done: First, any misalignment between the conduit, usually encased in concrete, and the piece of electrical equipment must be rectified; secondly, on an installation of this type sufficient clearance should be assured between the machine and the rigid conduit.

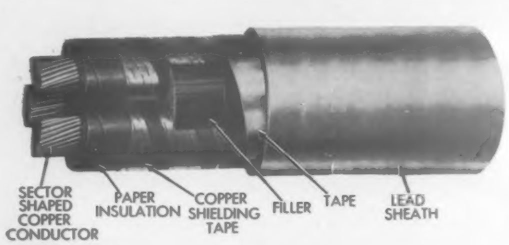
A slip joint (Figure 16) in the conduit is possibly the simplest method of providing flexibility for alignment and clearance for the installation. The conduit is so arranged that a short length of larger diameter conduit is slipped over the conduit encased in the concrete and, after the pothead is installed, the short conduit is raised and screwed into the conduit coupling on the pothead. Possibly no other problem of a pothead installation has been the cause of more trouble in the field than that of obtaining the necessary flexibility between the equipment and the pothead or cable termination when conduits are employed.

Cable capacity affects pothead choice

Selection of a pothead for an installation is influenced by the actual size of the copper conductor. Kva or number of amperes that is to be carried by a cable does not necessarily determine the size of the copper conductor. Other factors limit cables that are just as pressing in specifying copper conductor requirements as the actual load. For instance, cables traveling through well-ventilated and cool underground ducts are usually able to carry much higher ampere loads than cables in a closed conduit run which is encased in a concrete wall next to a hot boiler room. Therefore, copper size or diameter must be known before specifying a pothead.

Commercially procured potheads, based on specific installation requirements, can be obtained with copper terminals properly bored for soldered connection. Solderless internal connections have been developed for some sizes of cables, but these are physically limited to sizes determined by space inside the porcelain tube.

To complete the termination, the proper type of connection



PAPER INSULATED power cables for equipment above 15 kv require special treatment in construction and termination to prevent corona and provide good termination. **(FIGURE 18)**

should be made to the top of the pothead terminal. If copper bus bars are used, a blade type of connection will be the most practical. However, if standard stranded copper conductors are to be connected to the pothead terminal, the lugs should be drilled according to the copper conductor dimensions.

Voltage rating of the pothead should be coordinated with the insulation level of the cable. Common practice recommends a pothead having a rating low enough so that the insulator will flash over before the insulation of the cable is broken down.

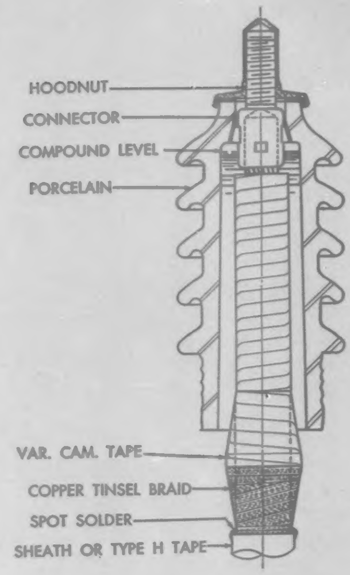
Utilization of direct burial cables affords several ways of terminating. The most suitable, and by far the simplest to make, is the pothead with an armor clamp. This armor clamp (Figure 17) is installed on the base of the pothead in the same manner as the conduit coupling. As with the conduit coupling, a stuffing box or clamping ring type of entrance is required to seal the base of the pothead. The armor clamp can be adjusted within certain limits to the various sizes of cables. However, submarine or borehole cables having wire armor require a special type of armor clamp.

Stress relief important

Stress relief exerts considerable influence in any discussion of cable terminations. Normally, stress relief is not required on voltages below the 15-kv class. This type of equipment, as well as cables, requires considerable precautions for the prevention of corona.

A suitable cable, requiring special treatment to properly terminate the shielding tape or braid used in its construction, has been developed for this voltage range. It consists of a thin copper tape (Figure 18) wound helically around each conductor of a three-conductor cable over the paper insulation which must be properly handled inside the pothead to make an effective termination. Another paper insulated cable has a layer of carbon coated paper wrapped around the insulated conductor which acts as a shielding tape. Special treatment is again necessary to obtain good cable termination.

Operational difficulties are sometimes encountered when special cables are used. For instance, on one generator installation where the carbon coated paper shielding tape was used in the cable construction, the installation crew either overlooked or did not appreciate the need for removing the shielding tape before completing the termination. The situation was further aggravated by the fact that no stress relief



STRESS RELIEF cones of some type are necessary for proper termination when special cables are used. A typical example of an effective stress relief cone is shown above. **(FIGURE 19)**

cone was added. Consequently pothead failures began to occur shortly after the generator began to operate. These persisted until someone found and corrected the omissions.

If efficient, uninterrupted operation is to be obtained, some sort of stress relief cone should be made to properly terminate shielding tape (Figure 19) in the pothead. Exact location and shape of the stress cone is somewhat of a controversial issue. Suppliers of potheads will usually furnish drawings of stress relief cones designed to satisfy particular applications.

Summary

Cables, entrance fittings, potheads, and the conditions under which they are to be used should be considered seriously before a method of cable termination is chosen as the most practical and economical for an installation. These precautions apply whether an industrial concern has its own engineers supervise cable termination or whether the manufacturer of the equipment is consulted and authorized to provide necessary potheads and accessories. In addition to the preceding requirements, space limitations, location of equipment and anything else that might affect the installation of potheads or cables should be properly evaluated to achieve efficient and economical cable terminations.

CORRECTION: An oversight failed to give credit where credit was due in the case of "Emergency Sources Boost Power Supply," by Prof. Charles F. Dalziel, Third Quarter, 1948, ELECTRICAL REVIEW. Photograph of Salt Springs Reservoir, page 5, was supplied by the Pacific Gas & Electric Co., California, while the induction motor picture on page 6 was made possible through the courtesy of the California Electric Company, San Francisco, Calif.

O. A. HAAS
BLOWER & CONDENSER
C

ALLIS-CHALMERS "Certified" Service

A BREAKDOWN on this 39-year-old Allis-Chalmers fan motor crippled operations at the plant of an important midwest electric utility. Immediate repair was vital. The Chief Engineer called the nearest Allis-Chalmers Certified Service shop. They picked up the rotor and returned it ready for service in less than twenty-four hours.

This is the kind of emergency cooperation you can expect from every Allis-Chalmers Certified Service shop. On everyday repairs and maintenance too, your Allis-Chalmers Certified Service shop will give you prompt service on Allis-Chalmers motors, pumps and transformers, using factory approved methods and parts. Every Allis-Chalmers Certified Service shop has been selected for skilled, personal, careful workmanship, adequate equipment and *service mindedness.*

HOW TO FIND NEAREST SERVICE SHOP

Allis-Chalmers Certified Service shops are located in major industrial centers throughout the country. New shops are being appointed continuously and most smaller centers will soon be covered. To find the shop nearest you, call your closest Allis-Chalmers District Office.

A 2543

MOTOR DELIVERIES GREATLY IMPROVED

Many types of Allis-Chalmers Motors are now in stock! Many other types are available on short delivery! For motors from 1 to 200 HP, check your nearest Allis-Chalmers Authorized Dealer. For motors larger than 200 HP, check with the nearest District Office. You may be able to get what you need sooner than you think.

ALLIS-CHALMERS

Pioneers in Power and Electrical Equipment from Generation through Utilization